VOL. XXXVI. — No. 11. NOVEMBER 1959.

Monthly Bulletin of the International Railway Congress Association

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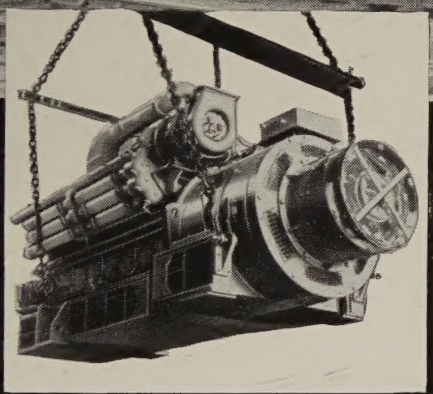

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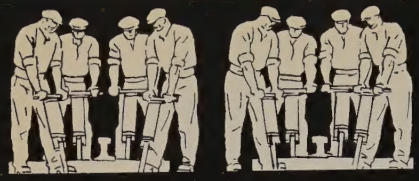
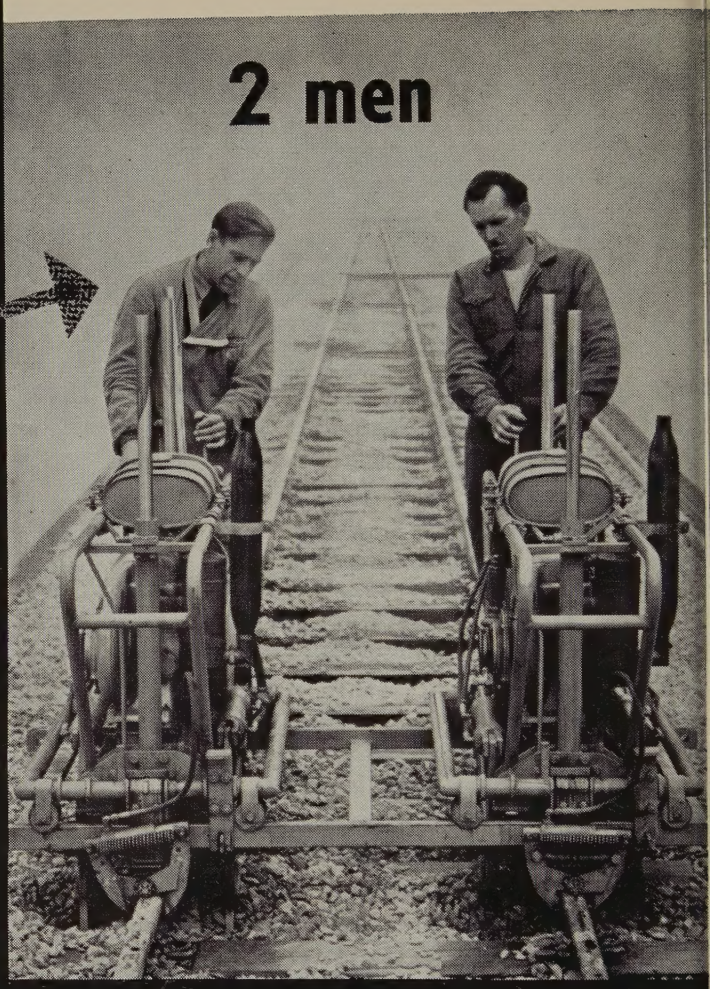


8 men

2 men



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MONTHLY BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

(ENGLISH EDITION)

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An edition in French is also published.

Vol. XXXVI. — No. 11. November 1959.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

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INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

ENLARGED MEETING OF THE PERMANENT COMMISSION
(NEW DELHI, 1959).

SECTION II. — Locomotives and rolling stock.

QUESTION 2.

Problems met in the design of multi-current rolling stock. Existing types : experimental results. Future developments.

SPECIAL REPORT,

by J. J. Jonker,

Head of the Rolling Stock and Electrical Installations Department of the Netherlands Railways (Utrecht).

1. Introduction.

In the *Bulletin* for October 1959, the Reports concerning the Administrations corresponding in French and English, respectively, have been published simultaneously.

A questionnaire had been prepared at the time, at very short notice. Although the questionnaire went into great detail, it would appear now that even more questions should have been included. Also, some of the questions do not seem to have been sufficiently clear. As time was short, it was unfortunately impossible to put supplementary questions prior to the drafting of the two Reports mentioned above.

The purpose of the present Report is to combine the two Reports mentioned above, and to examine whether it is possible to draw from them certain teachings which might be presented as draft summaries to the New-Delhi Meeting.

The replies received from the Administrations showed that :

1) they have a number of motive power units in service, under construction, or in the planning stage, which are able

to work with more than one type of current;

2) there are, therefore, circumstances for which the Administrations deem it useful to provide such motive power units.

In the present Report, the attempt will be made to give, in a logical manner, a brief synopsis of the vehicles in operation and, by way of conclusion, to survey the reasons why these vehicles have been, or will be, taken into operation.

In surveying the motive power units in operation, only those aspects of the problem will be discussed which have a bearing on the aptitude of the vehicle to work with more than one type of current. This can most easily be done by describing the differences between these vehicles and comparable motive power units which can only work with one of the types of current.

This method has in particular the advantage to show directly the complication resulting from the working with more than one current system.

Comparing on the other hand the weights of the units, it will also be possible to have an opinion of their cost, as well as of the additional cost due to the possibility of operating with more than one current system. It is however advisable to be careful in this field, owing to the fact that several factors, especially the importance of series construction, are liable to influence the cost.

2. Classification of multi-current motive power units.

Multi-current motive power units are power units able to work with more than one type of current. The Administrations indicate the following combinations :

a) D.C. systems of different voltages;

b) A.C. systems of different voltages but the same frequency;

c) A.C. systems of different voltages and frequencies;

d) one or more A.C. systems and one or more D.C. systems;

e) one three-phase current system and one D.C. system.

The order in which these combinations are listed is the one most easily followed in compiling the present Report.

3. D.C. systems for different voltages.

The Netherlands Railways (N.S.) and the Belgian National Railways (S.N.C.B.) indicate that they have 12 Benelux type railcars suitable for working with 1 500 V D.C. as well as 3 000 V D.C.

3.1. *Traction equipment.*

The principle is well known. The traction motors are D.C. motors for 1 500 V.

On S.N.C.B. lines, the four motors are connected in series, when running in series, whilst the parallel connection consists of two series-connected sets of two parallel-connected motors.

When in full series combination, the motors work with 750 V and, when in full parallel, with 1 500 V (fig. 1).

On N.S. lines, the series connection consists of two parallel-connected sets of two series-connected motors. With parallel connection, all the motors are connected in parallel. In the former case, the motors work with 750 V, and in the latter with 1 500 V.

Compared with the 1 500 V D.C. railcars, the motors are heavier, as they must be insulated for 3 000 V instead of 1 500 V in relation to earth. The same applies to cabling and contactors.

Compared with a 3 000 V D.C. railcar, the cabling is more heavy as the copper sections are larger and some contactors must be able to carry twice the current intensity.

These considerations, however, are only valid if the same power must be developed on both systems, which is in fact the case here.

It must also be noted that this is only possible when the highest tension is a whole multiple of the lowest tension, which is the case in the countries belonging to the I.R.U. (U.I.C.).

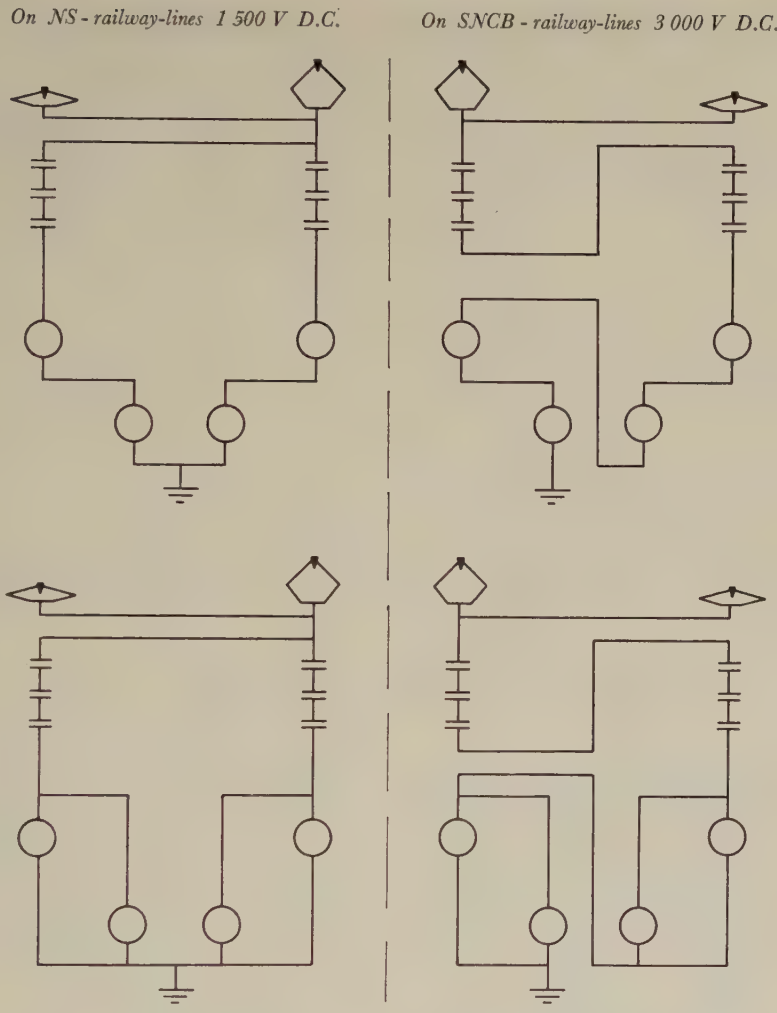


Fig. 1. — Main circuit of the N.S.-S.N.C.B. electric trainsets « Benelux ».

3.2. *Current collection.*

As far as the pantographs are concerned, there is no standardisation, so far, in Western Europe. As regards D.C. pantographs, there are, inter alia, the following differences.

A Committee of experts, under the auspices of O.R.E. Commission A3, is at present trying to improve this position. It is obvious that countries which, for space reasons, e.g. in the tunnels, have adopted a narrow pantograph cannot easily abandon it in view of the expenditure incurred in widening the structure gauge. On the other hand, countries which have adopted a wide pantograph cannot easily admit a narrow one as it would be necessary to modify the catenary if contact is to be maintained. Another

	S.N.C.B.	F.S.	S.N.C.F.	N.S.
Catenary voltage	3 000 V	3 000 V	1 500 V	1 500 V
Width of pantograph	1.76 m	1.43 m	1.96 m	1.95 m
Material of strips	carbon	copper	winter : steel summer : copper	impregnated carbon with lead and copper
Maximum height of contact wire	6.2 m	5.8 m	6.5 m	5.75 m
Maximum height of raised pantograph	6.56 m	—	not stated	5.88 m
Pantograph pressure	7.5 kg	8 kg	9 kg	railcars : 9.5 kg locomotives : 12 kg
Number of strips	2	1	4	3

difficult point is the question of the material for the wearing strips. Steel strips entail greater wear of the contact wire but permit a more important current collection per contact point. With long trains, which must be heated when stationary, the heat accumulation at the contact point may become critical.

In view of these differences, there are very good reasons why it will be difficult for the different Administrations to compromise. However, as long as these differences continue, current collection will constitute a problem for motive power units capable of working with more than one type of current.

In the case of the Benelux multiple-unit sets, different pantographs were required for working on N.S. lines and S.N.C.B. lines, respectively. Compared with the corresponding N.S. railcars as well as S.N.C.B. railcars, there is thus one pantograph more on the roof. In the case of the multiple-unit sets, space considerations do not come into account, but this entail additional weight and cost. For locomotives, incidentally, a new type of pantograph has recently been developed where it is possible to mount two pantographs in the space previously required for one, so that four pantographs can be mounted on a locomotive without difficulty.

3.3. *Auxiliaries.*

The auxiliaries must likewise be so designed that they can be switched over for either system. Single motors must therefore be replaced by two motors which can be connected in series or in parallel. This, it will be appreciated, represents a complication. In the case of the Benelux multiple unit sets, this solution has only been used in one instance, namely the motors which drive the compressor and the auxiliary generator. The latter supplies 100 V D.C. for the other auxiliaries, battery charging, lighting, etc. (fig. 2).

As regards heating, high-tension radiators, divided into two sets per car, have been installed below the seats. These sets can be connected in series for 3 000 V, and in parallel for 1 500 V working.

3.4. *Protection against wrong connection.*

It is obviously more dangerous to bring the equipment in the 1 500 V D.C. posi-

tion into contact with a 3 000 V catenary than vice versa . That is why, if that happens, a protection device has been provided which will trip the circuit breakers associated with the traction motors, the heating circuits, and the motor-generator-compressor unit. Two no-volt relays are used for this purpose with these equipments (fig. 3).

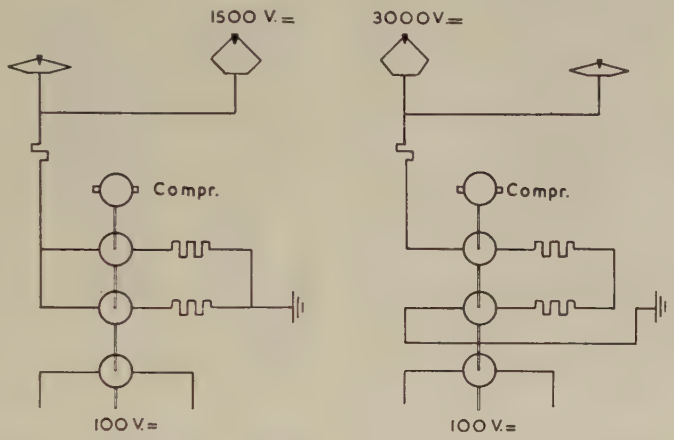


Fig. 2. — Motor generator compressor of the N.S.-S.N.C.B. electric train sets « Benelux » 1 500 V D.C./3 000 V D.C.

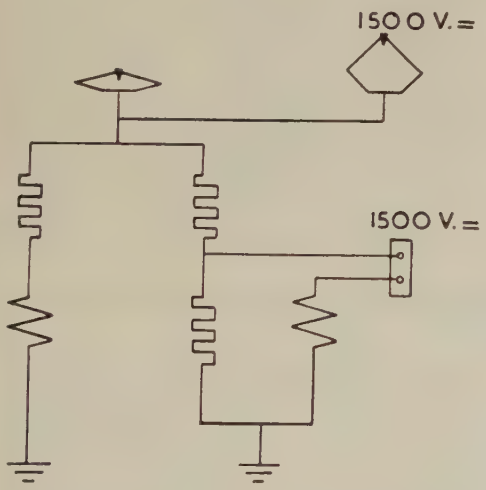


Fig. 3. — Protection against fault connection in the high voltage plant of the N.S.-S.N.C.B. electric train sets « Benelux » 1 500 V D.C./ 3 000 V D.C.

3.5. *Total weight.*

The Netherlands Railways possess railcars with very similar outward appearance but rather different internal equipment so that any precise comparison of weights is impossible. An otherwise comparable 1 500 V railcar weighs 110 t, compared with the 115 t of the Benelux car. A 1 500 V traction motor weighs 1 600 kg compared with the 2 200 kg of the Benelux motors.

4. A.C. systems for different voltages but the same frequency.

B.R. have placed orders for a total of 351 motor coaches and 100 locomotives, which will work with 25 kV, 50 cycles as well as with 6.25 kV, 50 cycles.

Several types of equipment are being developed generally on similar lines as regards the voltage changeover system. The particulars which follow relate to 112 motor coaches, to work in 4-car sets, of which 60 are in service already.

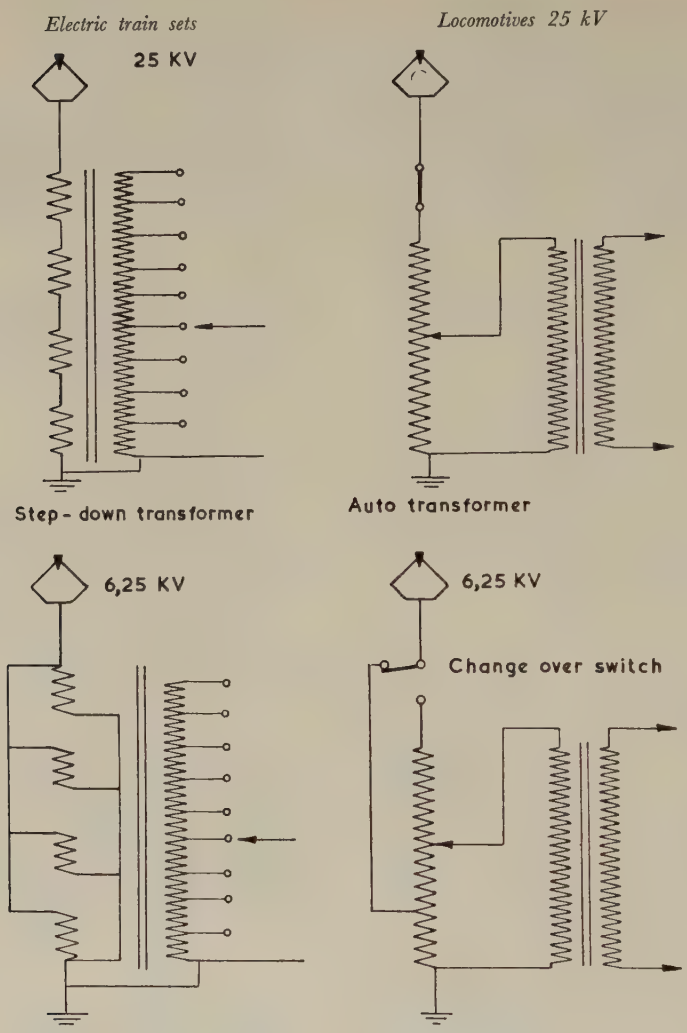


Fig. 4. — Basic diagram of the transformer-connections. — B.R. electric train sets and some locomotives.

4.1. *Traction circuits.*

To enable these vehicles to work with both voltages, the primary transformer winding of the motor coaches is subdivided into four parts which are connected in series on 25 kV, and in parallel on 6.25 kV (fig. 4). Speed control is effected by means of contactors and coils on the secondary side of the transformer. This voltage is applied to the motors after rectification in push-pull connection.

By thus adapting the primary side of the transformer to the contact wire voltage, the primary winding carries the same load under both systems.

Compared with a normal transformer for 25 kV, 50 cycles, the transformer is hardly heavier. There are no more than three supplementary tappings on the primary side. In addition, the connections

to the primary must be switched over so that a supplementary changeover switch is required.

On some of the 100 locomotives now on order, British Railways intend to try out a speed control on the primary side. In this case, they will connect the primary winding like an autotransformer for 6.25 kV (fig. 4). As far as the primary winding is concerned, this connection scheme is less favourable than the first method, and the transformer becomes heavier in consequence. On the other hand, the changeover itself is simpler. With the commutation taking place on the primary side, the traction motors, rectifiers, secondary cabling, etc. remain in the same condition with both voltages. In both cases, the air circuit breaker has the same rupturing capacity, and there is no need to carry out any structural modifications compared with a motive power unit designed for 25 kV, 50 cycles only.

4.2. *Auxiliaries.*

The auxiliaries such as oil pump, cooling fans for transformer and rectifiers, motor-generator set and heating are connected to a tertiary winding on the transformer. The compressor is likewise connected to the tertiary winding, but through the intermediary of a rectifier. As the primary winding is appropriate to the catenary voltage, these equipments work under the same conditions so that their aptitude to work with both voltages does not give rise to any problems in this case.

4.3. *Protection against wrong connection.*

Before (at a distance from 15 to 30 m according to the speed) passing a point where either the voltage or the phase changes, the power equipment is automatically switched off, the switchover being actuated by an electro-magnetic device placed by the side of the rails. This device energizes a relay, which trips the pneumatic circuit breaker. The vehicle then coasts over three successive neutral sections. The catenary voltage is measured by means of voltage relays. As the neutral sections are passed without current, there is no danger of « pumping ». When the voltage changes, the primary transformer winding is reconnected. A short distance (15 to 30 m) beyond the neutral sections, another electro-magnetic device has the effect of re-closing the pneumatic circuit breaker by means of a relay. Passing from one system to the other is thus a wholly automatic operation.

4.4. *Total weight.*

The equipment of these vehicles for two voltages does not really entail any weight increase. British Railways estimate that, due to this installation, the construction cost of these vehicles is about 3 % higher.

5. Motive power units for different A.C. voltages and frequencies.

The Reports contain the descriptions of the following locomotives; only the last of these is not yet in operation :

Type of locomotive	*Administration*	*Suitable for*
BB 30001/2	S.N.C.F.	15 kV, 16 2/3 c/s and 25 kV, 50 c/s
BB 30003/4	S.N.C.F.	dto. dto.
Ee 3/3 II 16501/02	S.B.B.	dto. dto.
Ee 3/3 II 16503/09	S.B.B.	dto. dto.
Ee 3/3 II 16505/06	S.B.B.	dto. dto.
E 1051.01	Oe.B.B.	dto. dto.
E 320	D.B.	dto. 20 kV and 25 kV, 50 c/s

None of the Reports mentions any rail-car suitable for working on A.C. systems with different voltages and frequencies.

The principal data of these locomotives are summarized below. For other details, reference should be made to the *Congress Bulletin* for the month of October 1959.

The only ones among these A.C. locomotives which have A.C. traction motors are these: BB 30001/02, Ee 3/3 16503/04

Power and weig

	Dual-frequency					
Locomotive numbers	*S.B.B. 16 503*	*S.B.B. 16 501*	*S.B.B. 16 505*	*Oe.B.B. E 1 051*	*S.N.C.F. 30 001*	*S.N 30*
Power (one-hour rating)	735	690	690	2 800	4 460	5 1
Transformer regulation	LT	LT	LT	LT	HT	H
Rectifier connection	—	push-pull	push-pull	—	—	bri
Number of traction motors	1	1	1	4	4	
Total weight (metric tons)	46.0	45.0	47.0	82.0	85.0	81
Total weight of the electrical installations, including the motors					39.6	36
Total weight of the traction motors	3.6	2.9	3.2	15.6	18.4	13
Weight of the electrical installations, excluding the motors					21.2	22
Weight of transformer	4.9		8.2	8.8	13.1	12
Weight of the remaining electrical equipment					8.1	9
Total weight in kg pr. H.P.	62.5	65.2	68.0	29.3	19.0	15
Total weight of the electrical installations, including the motors, in kg pr. H.P.					8.9	
Total weight of the motors in kg pr. H.P.	4.9	4.2	4.6	5.6	4.1	
Weight of the electrical installations, excluding the motors, in kg pr. H.P.					4.8	
Weight of transformer in kg pr. H.P.	6.7		11.9	3.1	3.0	
Weight of the remaining electrical equipment in kg pr. H.P.					1.8	

and E 1051.01. The four others are equipped with rectifiers and traction motors for undulating current. For each of these two solutions, the importance of the resulting difference compared with locomotives exclusively destined for either 15 kV, 16 2/3 cycles or 25 kV, 50 cycles will be examined.

ous locomotives.

		A.C./D.C.				*1 500 V D.C.*	*15 kV - 16 2/3 c/s*		*25 kV - 50 c/s*
C.F. 004	*D.B. E 320*	*S.N.C.F. 16 500*	*S.N.C.F. 20 004*	*S.B.B. 10 851*	*J.N.R. ED 46*	*S.N.C.F. 9 400*	*D.B. E 10*	*D.B. E 41*	*S.N.C.F. 16 500*
20	3 520	3 500	2 970	2 300	1 970	3 050	5 000	3 250	3 500
T	HT	HT	—	HT	—	—	HT	LT	HT
dge	bridge	push-pull	push-pull	bridge	push-pull	—	—	—	push-pull
	4	2	2	4	2	2	4	4	2
.0	84.0	69.0	69.0	84.0	64.0	60.8	85.0	66.0	68.0
.7		29.9	31.8			23.6			28.7
.9	12.8	9.3	11.0		6.5	12.6	15.7	10.4	9.1
.8		20.6	20.8			11.0			19.6
.4	12.0	7.7	5.7		4.7		11.8	8.0	8.5
.4		12.9	15.1			11.0			11.1
.6	23.8	19.7	23.2	36.7	32.7	20.0	17.0	20.3	19.4
.7		8.5	10.7			7.7			8.2
.7	3.6	2.6	3.7		3.3	4.1	3.1	3.2	2.6
.0		5.9	7.0			3.6			5.6
.4	3.4	2.2	1.9		2.4	—	2.4	2.5	2.4
.6		3.7	5.1			3.6			3.2

5.1. *Current collection.*

Although this is not justified by a difference in voltage and frequency there are differences between the pantographs of Oe.B.B., D.B., S.B.B. and S.N.C.F. The main differences among them are tabulated below :

	Oe.B.B.	*D.B.*	*S.B.B.*	*S.N.C.F.*
Type of current — *Voltage*	15 kV	15 kV	15 kV	25 kV
Type of current — *Frequency*	16 2/3	16 2/3	16 2/3	50 c/s
Width of pantograph	1.95 m	1.95 m	1.32 m	1.60 m
Material of wearing strips	carbon	carbon	aluminium	steel
Maximum height of contact wire	6.30 m	6.50 m	6.00 m	6.50 m
Maximum height of raised pantograph	not stated	6.70 m	not stated	not stated
Pantograph pressure	5.5 kg	9.0 kg	5.5 kg	7.0 kg
Number of strips	2	2	2	2

These differences have obviously no influence on the design of the pantographs of the S.B.B. shunting locomotives Ee 3/3 16501/06 which are exclusively used at Basle. The S.N.C.F. locomotives BB 30001/04, which work on the Luxembourg-Basle line, have two French type pantographs which have a greater width than the Swiss pantograph; but their use has been specially authorized at Basle. On the Oe.B.B. locomotive E 1051.01, which works between Passau and Vienna, it is also possible to make do with one type of pantograph. In contrast, the D.B. locomotive E 320, which must also be able to run over the 25 kV, 50 c/s lines of the S.N.C.F., must be equipped with an additional narrow S.N.C.F. pantograph, apart from the large D.B. pantograph.

5.2. *Traction equipment.*

5.2.1. *Locomotive with A.C. traction motors.*

The S.N.C.F. locomotives BB 30001/02 have a transformer with high-tension control, operated by sliding contacts (cf. basic diagram, fig. 5). In contrast, the S.B.B. locomotives Ee 3/3 16503/04 (cf. basic diagram, fig. 6) and the Oe.B.B. locomotive 1051.01 have a low-tension control with contactors.

Compared with locomotives intended for working on 16 2/3 c/s only, the electrical installation becomes heavier. The transformer becomes heavier because the primary winding and the tappings must be insulated for 25 kV. It is also necessary to take the lay-out at 50 c/s into account, and to increase the subdivisions of the windings for this purpose. In order to avoid excessive self-induction at 50 c/s, one will have to be content, at 16 2/3 c/s, with a lower short-circuit voltage. The traction motors must be able to satisfy the most exacting requirements of 50 c/s traction from a commutation point of view, and will therefore become about 20 % heavier. In order to obtain good commutation at both frequencies, there

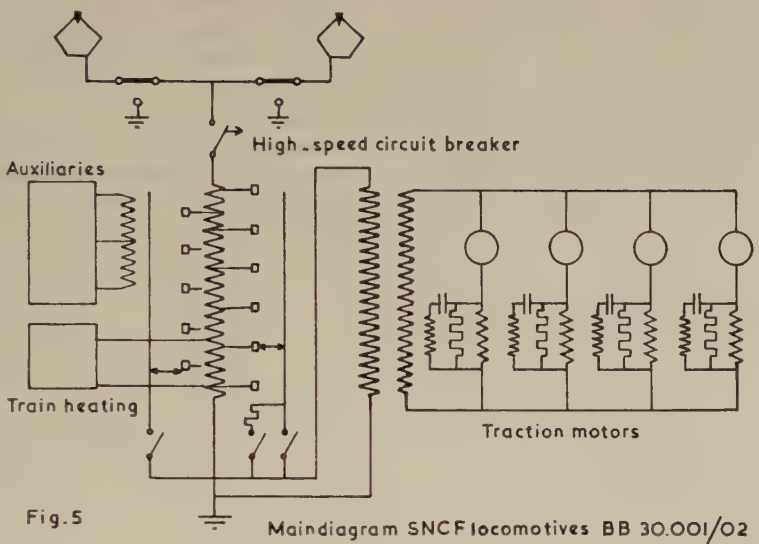


Fig.5 Maindiagram SNCF locomotives BB 30.001/02

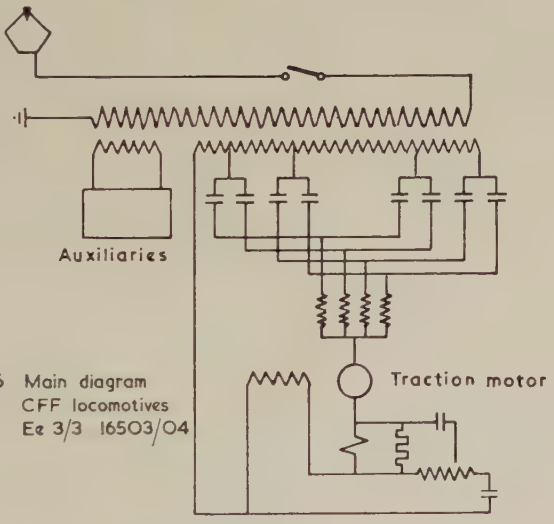


Fig.6 Main diagram CFF locomotives Ee 3/3 16503/04

must be a possibility of modifying the degree of shunting of the interpoles, when switching over from 16 2/3 to 50 c/s. If a locomotive suitable for two frequencies is compared with a locomotive suitable for 25 kV, 50 c/s only, the transformer is found to be heavier. The lower frequency calls for an increase in the flux; on the other hand, the lower primary voltage and the higher induction which can be allowed at 16 2/3 c/s limits the flux. The weight will be about twice that

required for a 50 c/s transformer of the same type.

The motors are 50 c/s motors for which the working conditions will be better at the lower frequency, provided that the degree of shunting of the interpoles is modified. On the BB 30001 locomotive, the auxiliary poles are shunted at 50 c/s

The rectifier locomotives should first be compared with locomotives with A.C. motors. Table 1 shows the weights of all the locomotives comprised in the comparison.

The comparability of the figures supplied by the different Administrations is very good. Certain differences may,

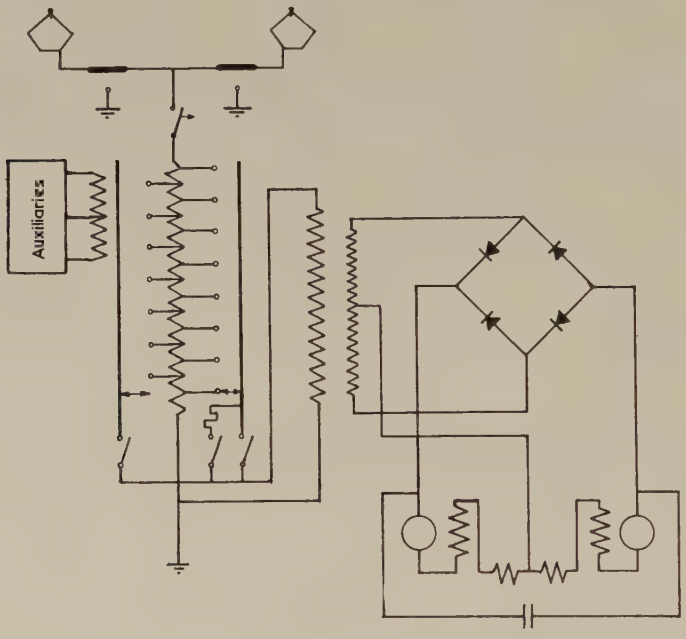


Fig. 7. — Main-circuit. — S.N.C.F. locomotives BB 30003/04.

by 0.0038 ohm, and at 16 2/3 c/s by 0.0017 ohm. It goes without saying that these considerations are only valid if the locomotive is required to develop the same power on both supply systems.

5.2.2. *Rectifier locomotive.*

The S.N.C.F. locomotives BB 30003 and 30004 (cf. basic diagram, fig. 7) have a transformer with high-tension control, whilst the S.B.B. locomotives Ee 3/3 16501 and Ee 3/3 16505 have low-tension control.

however, arise from the fact that one Administration has included in the calculation the weight of components which another Administration may have left out.

For the comparison, it is therefore always preferable to use, as far as possible, the figures supplied by the same Administration. From this point of view, perfect comparability exists, on the one hand, between the S.N.C.F. locomotives BB 20004 and BB 9400, on the other hand, the S.N.C.F. locomotives BB 16500 adapted

or not to multi-current and finally the S.N.C.F. locomotives BB 30003/04, as their mechanical equipment is more or less the same.

The German Federal Railways state that the transformer of their E 320 locomotive, which feeds the traction motors through the bridge-connected rectifiers, is 20 % heavier than would be required for a direct feed of the motors. The Japanese National Railways mention that the transformer of their ED 46 locomotive feeds the traction motors through the intermediary of a push-pull connection so that the power capacity of the windings amounts to 141 % and the transformer weight to 110 % compared with a normal transformer. However, if the transformer feeds the motors through a bridge connection there is no reason for the transformer to be heavier. This opinion is shared by the S.N.C.F. on the strength of their experience with the transformers of the BB 30003/04 locomotives which feed the traction motors through bridge-connected rectifiers. With push-pull connection, the S.N.C.F. expect a slightly increased transformer weight. It is only on the face of it, that the opinions of the German Federal Railways on the one hand and those of the J.N.R. and S.N.C.F. on the other hand differ. The transformer which feeds the traction motors through bridge-connected rectifiers is heavier than a transformer which supplies the same power to A.C. motors, seeing that, in the former case, the secondary voltage of the transformer is about twice as high. It is not advisable to make comparisons in Table 1. The transformer of the E 41 locomotives has two windings and low-tension regulation, which permits a lighter construction than a transformer of the E 320 which has three windings and high-tension regulation.

As far as the traction motors are concerned, the same leading principles are obviously again encountered as with the traction motors of the 25 kV, 50 c/s locomotives where one is trying to avoid, on the one hand, the undulation of the flux and hence the commutation difficulties by shunting the main field with a non-inductive resistance, e.g. on the E 320 (4 %), while on the other hand, it is desired that the flux of the main poles and interpoles has the same phase and the same wave form. The examination of this problem, however, is outside the scope of the present report, as it is not a specific multi-current problem. As regards the weights of the traction motors, it should be pointed out, firstly, that the weight of a D.C. motor may be lower than that of a corresponding A.C. machine because the specific loads can be higher, and secondly, that it is necessary to limit the current in the rectifiers and to increase the voltage at the motors which has the effect of increasing the thickness of the insulation.

It should also be noted that the number of poles plays an important part. It follows from the answers received that the traction motors of locomotives suitable for two frequencies are lighter when they are fed by rectifiers than when they are fed by A.C. It is not possible to determine the difference in per cent. When comparing the motors of BB 30001/02 with those of BB 30003/04, it is also necessary to take into account the difference in the conception of these two types which have four and two motors, respectively. When comparing the traction motors of the D.B. locomotive E 320 with those of the Japanese locomotive E 41, it will be noted that the outputs are more or less the same, that the weights of the motors of E 320 is greater, but that the armature diameter of the motors of E 41 is greater.

When comparing the weights, the weight of the rectifier equipement has an unfavourable influence. This is more marked for excitrons and ignitrons than for rectifiers of the semi-conductor type.

The technique of this latter type of rectifiers is still new, and is being continuously improved.

With the E 320 locomotive, an interesting innovation consists in the protection

of the elements as a whole, and of each element individually, against overloads from external sources and overloads due to damage to one element. The disconnection is carried out in the required branch of the rectifier bridge at the moment at which the current circulating in the bridge is reduced to zero. These protections may be reinforced pneumatically after tripping. Moreover, as each set of motors is, with these locomotives, fed by a rectifier bridge, the effect of the operation of a protection device will be confined to the suppression of a quarter of the total tractive effort (see also the Report in the *Congress Bulletin* for October 1959). But this is not a problem specifically concerned with multi-current traction.

The working frequency of the rectifiers is irrelevant except that it has a bearing on the coils of the ignition apparatus of excitrons and ignitrons; solutions are, however, available where the complexity and weight of this apparatus are not greatly increased.

As already mentioned, the undulation of the current presents a problem with traction motors.

In this respect, the bridge connection of the rectifiers represents the most favourable solution. In contrast, the bridge connection is unfavourable as regards the auxiliary equipment of the excitrons and ignitrons, as the cathodes do not have the same voltage.

It is therefore the practice to use smoothing coils to decrease the undulation of the flux for all vehicles designed for two frequencies. These coils are less effective at 16 2/3 c/s than at 50 c/s; fortunately, they are less important with 16 2/3 c/s because the induced E.M.F. of transformation is three times smaller. They are therefore rated for the frequency of 50 c/s, and it is necessary to take the inductances of the transformer into account. With the BB 30003/04 locomotives of the S.N.C.F., the harmonics percentages is 50 % whilst on the four Ee 3/3 locomotives of the S.N.C.F., no more than 20 % are tolerated.

The information received by us shows that the weights of the rectifier locomotives do not differ greatly from the weight of locomotives equipped with A.C. motors; they are, if anything, slightly heavier compared with equivalent locomotives.

It should be noted in this connection that the torque of a rectifier locomotive is more regular, which permits, theoretically, a closer approach to the adhesion limit. The maximum tractive effort of the S.B.B. rectifier locomotives is slightly superior to that of the BB 30003/04 locomotives of the S.N.C.F., but slightly inferior to that of the BB 30001/02 locomotives.

5.3. *Air blast circuit breakers.*

At 16 2/3 c/s, the rupturing capacity of a circuit breaker is smaller than at 50 c/s. It must, however, be confirmed that it is adequate for all the lines on which the locomotives work.

5.4. *Auxiliaries.*

As far as the current supply for the auxiliaries is concerned, several different solutions are possible :

a) The Oe.B.B. use, for the auxiliaries such as compressor motor, oil pump, fans and the motor-generator set, a motor suitable for two frequencies. This solution is thus in keeping with that adopted for the traction motors;

b) The D.B. use, on the E 320 locomotive, auxiliary D.C. motors except in the case of the oil pump motor. The motors are supplied from a tertiary transformer winding through the smoothing coils and a set of bridge-connected silicon rectifiers. For testing purposes, these auxiliaries can also be fed at 220 V, 50 c/s, especially in the workshop.

This solution has also been adopted by the S.B.B. for their Ee 3/3 16501/06 locomotives, except that the current supply for testing purposes is 220 V, 16 2/3 c/s;

c) The D.B. have, however, made an exception in the case of the motor for the oil pump of the E 320 locomotive which is driven by a three-phase motor with a squirrel-cage armature rotating in the oil. With this arrangement, it is possible to eliminate the packing.

The third phase is created by a capacitance;

d) The battery charging current is supplied by a tertiary winding of the transformer, and rectification.

This solution has been applied by the S.N.C.F. to their BB 30001/04 locomotives.

All these auxiliaries are supplied from a third transformer winding. On none of the dual-frequency locomotives is there a change-over switch on the primary so that it is necessary to provide a change-over on the tertiary winding.

It has already become apparent that different solutions can be used simultaneously. It must be feared, however, that the equipment becomes more complicated under such conditions.

5.5. *Protection against wrong selection.*

The shunting locomotives Ee 3/3 16501/06 of the S.B.B. work at Basle station and must frequently change from the 25 kV, 50 c/s system to the 15 kV, 16 2/3 c/s system, and vice versa.

In the circumstances, it was desirable to provide an automatic switchover; since the same pantograph is used for both systems, the proposition was fairly simple.

When approaching a neutral section of the catenary, the circuit breaker must be opened by hand. If the driver forgets to carry out this operation, the operation is effected automatically by a magnet installed on the track. The changeover of the equipment is effected by frequency relays. In the case of the S.B.B. locomotives, the number of operative turns of the tertiary transformer winding feeding the auxiliaries is increased, and the shunting of the traction motors modified.

The BB 30001/04 locomotives of the S.N.C.F., which work between Luxembourg and Basle, are similarly equipped.

The E 320 locomotive of the D.B. is provided with a manually operated selection switch in the driving cab.

This switch permits the connection of the auxiliaries to a different number of turns of the tertiary winding. The master controller in the driving cab is fitted with interlocking devices so that, with 25 kV, it is only possible to reach notch 27 as well as five weak field notches, instead of notch 39 and five weak field notches with 15 kV.

Moreover, another combination of frequency and voltage relays is used for this purpose. If the catenary voltage and frequency do not correspond to the system selected, the circuit breaker is tripped. This locomotive can work with two frequencies and three voltages, and is equipped with one frequency relay and three voltage relays which measure the lowest voltage (minimum voltage relays). One of them will likewise cause the tripping of the circuit breaker if the voltage is too high.

5.6. *Brakes.*

The E 320 locomotive of the D.B. is equipped with a rheostatic brake which can work with all the current supply systems concerned, either separately or in conjunction with the air brake at speeds exceeding 20 km/h.

All the field winding are connected in series and are fed by a separate silicon rectifier. The armatures of the two motors installed in the same bogie are connected to the same resistance.

5.7. *Total weight.*

The two main types are fairly similar as regards weight. In principle, the dry rectifier locomotives can be made slightly lighter than excitron or ignitron locomotives.

In any case, however, they are more complicated and heavier than the corresponding locomotives for 15 kV, 16 2/3 c/s and 25 kV, 50 c/s.

6. Motive power units for one or more A.C. systems and one or more D.C. systems.

The Reports contain the descriptions of the following motive power units now in operation :

Motive power unit	*Administration*	*Suitable for*
Railcar A	J.N.R.	20 kV, 50 c/s; 1 500 V D.C.
Railcar B	J.N.R.	20 kV, 50 c/s; 1 500 V D.C.
Locomotive CC 25001/09 . .	S.N.C.F.	25 kV, 50 c/s; 1 500 V D.C.

The Reports also cover the following motive power units which are not yet in operation :

Motive power unit	*Administration*	*Suitable for*
Locomotive E D 46	J.N.R.	20 kV, 50 c/s; 1 500 V D.C.
Locomotive E F 30	J.N.R.	dto.
Locomotive BB 16500	S.N.C.F.	25 kV, 50 c/s; 1 500 V D.C.
Locomotive BB 20004/5 . . .	S.N.C.F.	25 kV, 50 c/s; 3 000 V D.C. and 1 500 V D.C.
Locomotive Ae 4/6 III 10851.	S.B.B.	25 kV, 50 c/s; 15 kV, 16 2/3 c/s and 1 500 V D.C.
Locomotive Ee 3/3 IV 16551/60	S.B.B.	25 kV, 50 c/s; 15 kV, 16 2/3 c/s; 3 000 V D.C. and 1 500 V D.C.
Railcar TEE II RAe 1051/54	S.B.B.	dto.
Railcar TEE	N.S.-S.B.B.	dto.

In this combination of one or more A.C. systems and one or more D.C. systems, all but one of the motive power units are equipped with rectifiers.

The exception is the CC 25000 locomotive of the S.N.C.F. which is equipped with A.C. 50 c/s traction motors. When running on 25 kV, 50 c/s lines, these

motors are fed through a transformer, with voltage regulation on the secondary side.

When running on 1 500 V D.C. lines, the current is supplied by a D.C. - A.C. rotary converter. In this case, the one-hour power rating amounts to only 10 % and the tractive effort to 56 % of the values realized on 25 kV, 50 c/s lines.

In fact, this is a locomotive designed for 25 kV, 50 c/s which has been enabled, by the addition of a converter, to cover short distances, at reduced power and tractive effort, over the 1 500 V D.C. lines. The capital costs for providing this facility are obviously lower than those which would be required to equip the locomotive for working at full power throughout.

6.1. *Traction circuits.*

As already mentioned, all the other motive power units are equipped with rectifiers.

There are, however, differences in the method of speed control. On the D.C. systems, all the motive power units are equipped with resistance type speed control. On the A.C. systems, it is possible to avoid this method of speed control, by regulating the voltage at the primary and secondary side of the transformer. That is what the J.N.R. are doing with their multiple unit coaches as well as with their locomotives. The S.N.C.F. do the same on their BB 20004/05 locomotives, and the N.S.-S.B.B. on their T.E.E. train sets.

The S.N.C.F. have resorted to high-tension regulation on their locomotives BB 16500 as a means of controlling the speed on the A.C. lines.

The S.B.B. will use high-tension regulation on their locomotive Ae 4/6 10851, and low-tension regulation on their T.E.E. II.

In addition, the S.B.B. will use on A.C. lines a regulation by means of rectifier grid control. Tests have been carried out in this respect on the shunting locomotives Ee 3/3 at Basle station. The scheme has not yet been finalized.

6.1.1. *Motive power units with resistance type speed control for A.C. as well as D.C.*

On A.C. lines, the use of resistances entails losses just as on D.C. lines. If there is no need for frequent starts, these losses are acceptable. They depend on the speed at which the resistances are cut out, and are approximately equivalent to the energy required to cover a distance of 5 to 10 km. On the other hand, the equipment can be simpler and lighter.

The schematic diagrams of the J.N.R. locomotives and motor coaches are shown in the October 1959 issue of the *Bulletin*.

The rectifiers are bridge-connected or push-pull connected. The schematic diagram adopted by N.S.-S.B.B. is also shown in the October 1959 issue of the *Bulletin*.

The S.N.C.F. locomotives 20004/05 (see basic diagram, fig. 8) must be able to function with 1 500 and 3 000 V D.C. As these locomotives have two motors only, it is not possible to adopt the solution, applied to the T.E.E. train of the N.S.-S.B.B., of connecting the motors in series-parallel and in parallel at 1 500 V, and in series and series-parallel at 3 000 V. With 3 000 V D.C., economic running steps are created by field weakening. In view of the limitation set by the undulation of the current, one must be content with six shuntfield notches.

At 25 kV, 50 c/s, the motors are also supplied with 1 500 V D.C. These motors are therefore heavier than those of the dual-frequency locomotive where the rectified voltage does not exceed 1 000 V. On 3 000 V D.C. systems, the motors must be insulated for a voltage exceeding that value (3 600 V, according to leaflet 600 OR of the U.I.C.).

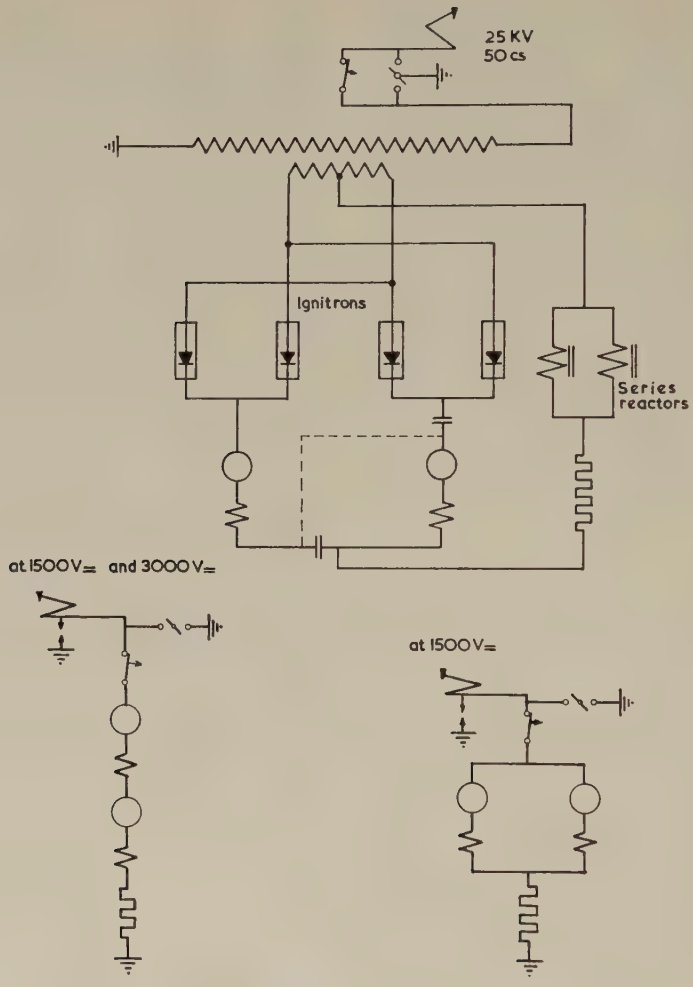


Fig. 8. — Basic diagram. — Locomotives BB 20004/05.

Because of the higher voltage, the transformer must also be insulated more elaborately on the secondary side, which would not be the case on a dual-frequency locomotive. The regulating equipment, which is relatively heavy, disappears but the resistances and corresponding contactors must be added.

6.1.2. *Motive power units which, on A.C. systems, are controlled by the modification of the transformer voltage.*

The locomotives 16500 of the S.N.C.F. work over D.C. lines at much reduced power: 930 HP instead of 3 440 HP (continuous rating) and 3 500 HP (one-hour rating).

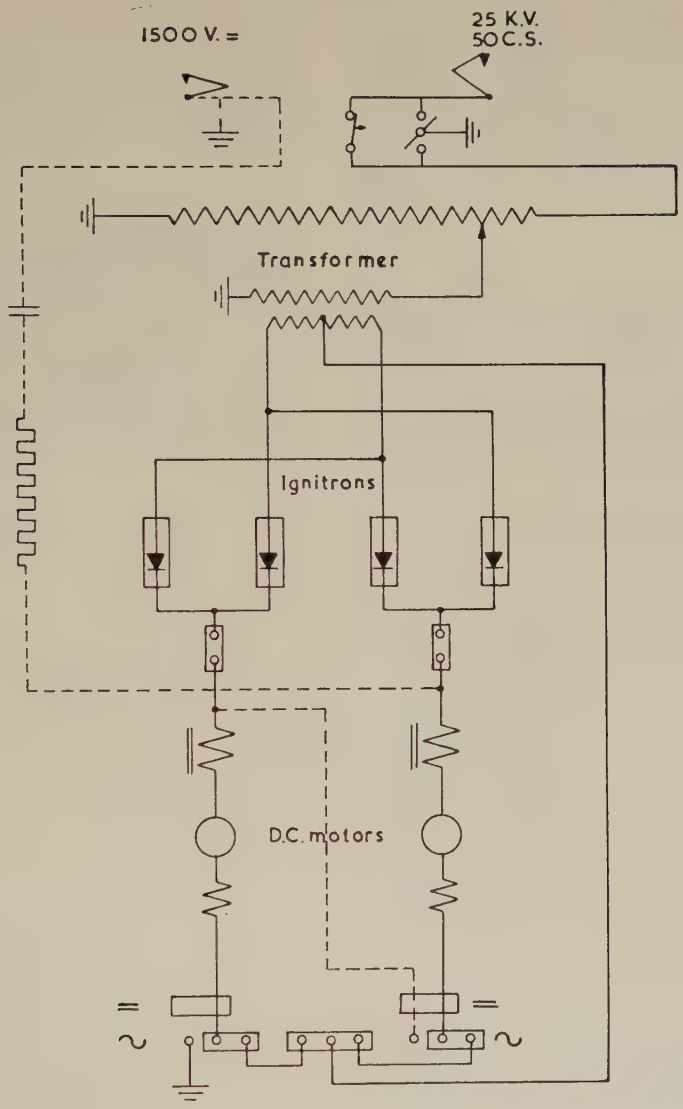


Fig. 9. — Main-circuit. — S.N.C.F. locomotives BB 16500.

The D.C. equipment (see basic diagram, fig. 9) can be of much simpler design than on the BB 20004/05 locomotives.

On the 1 500 V D.C. lines, the traction motors are connected in series, and there are 6 resistance notches.

On D.C. lines, the maximum voltage received by the traction motors is 550 V (per motor).

On A.C. lines, the maximum voltage applied to the motors reaches 1 200 V. The motors can therefore be lighter.

The transformer is subjected to conditions similar to those of the transformer of a dual-frequency locomotive equipped with rectifiers.

The C.F.F.-S.B.B. apply the same principles on their T.E.E. II and on their locomotives Ae 4/6.

6.2. *High-speed circuit breakers.*

In addition to the air blast circuit breaker required for the A.C. circuits, the motive power unit must be equipped with a high-speed circuit breaker for the D.C. circuits. As this circuit breaker is not suitable for separating the 25 kV tension from the 1 500 V circuits, it must be preceded by a disconnector and a selector switch.

On the J.N.R. locomotives, the air blast circuit breaker remains connected to the traction circuits when working on D.C. lines.

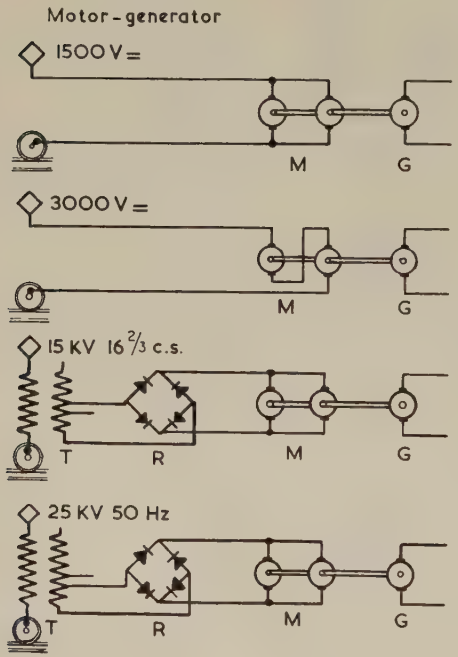
6.3. *Pantographs.*

As regards the pantographs, one is faced with the combined difficulties inherent in D.C. pantographs and A.C. pantographs. The difficulties of placing several pantographs on the roof of the same vehicle have led to a new type of design which permits the installation of two pantographs on the area occupied by a single pantograph of the old type.

It must also be noted that the J.N.R. use the same pantograph for 1 500 V D.C. and for 20 kV, 50 c/s.

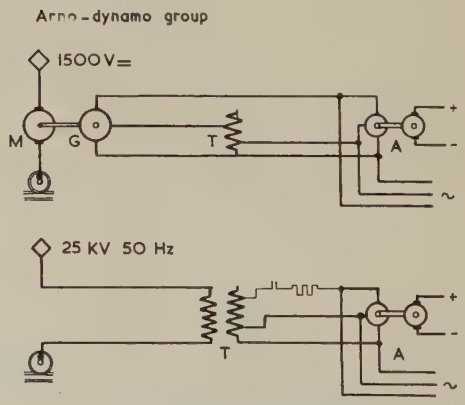
6.4. *Auxiliaries.*

As far as the auxiliaries are concerned, there are several possibilities. The principles are indicated in figures 10 *a*, 10 *b* and 10 *c*.



G. D.C. and A.C. generator.
T. Main transformer.
R. Rectifier.
M. Twin motor.

Fig. 10*a*.



A.C.-D.C. main convertor.
A. Arno-dynamo group.
T. Main transformer.

Fig. 10*b*.

In general, the current supply methods for auxiliaries can be classified as follows :

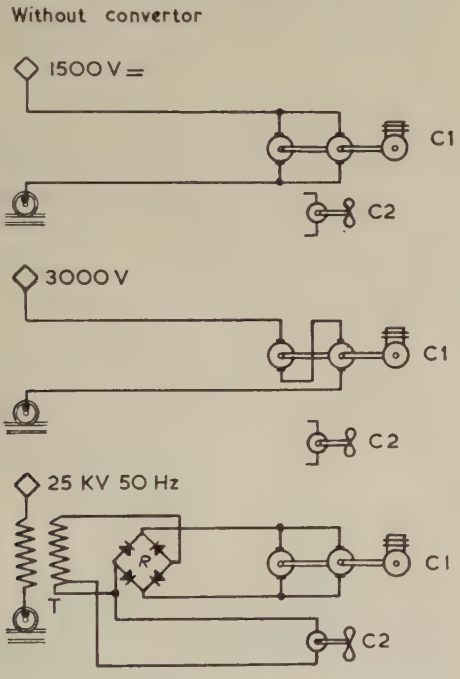
a) Low-tension feed by means of a motor-generator set;

b) Low-tension feed by means of an Arno set with generator;

c) D.C. high-tension feed for the auxiliaries required on D.C. lines, and A.C. feed for those required on A.C. lines.

When changing of current system occurs, the auxiliaries must for the greater number be commutated.

One often encounters combinations of these methods. For small motors, low-tension feed is preferred so that the third method is rarely applied to them.



T. Main transformer.

R. Traction rectifier.

C1. Auxiliaries working at all systems for example compressor.

C2. Auxiliaries working only at D.C. systems for example rectifier ventilator.

Fig. 10*c*.

By their very nature, all these converters give rise to complications. The use of rectifiers calls for the provision of smoothing coils, contactors, etc. Although the weight of the locomotive is not appreciably increased thereby, the locomotive becomes more complicated and more expensive.

6.5. *Total weight.*

These vehicles are heavier than dual-frequency motive power units. Their traction motors are heavier because of the higher feed voltage. They must be equipped with resistances and with a high-speed circuit breaker. The auxiliary equipment is heavier. Since the dual-frequency motive power units are already heavier than those working at 25 kV, 50 c/s and 15 kV, 16 2/3 c/s, the vehicles of this category will be heavier still.

As the use of rectifiers is already common practice on 50 c/s A.C. motive power units, the weight difference between a multi-current motive power unit and one designed for 50 c/s is smaller than the weight difference between such a unit and an equivalent unit designed for 16 2/3 c/s.

Compared with a motive power unit designed for 3 000 V D.C., the difference is considerable, as it is necessary to add the transformer, the rectifiers, the smoothing coils and the air blast circuit breaker.

Even greater are the differences compared with a motive power unit designed for 1 500 V D.C., because the motors are still heavier due to the need for insulating them for a higher voltage.

Apart from the increase in weight, it is also necessary to take into account the complication resulting from the change-over of the auxiliary equipment.

7. Motive power units for three-phase current and D.C.

The Italian State Railways (F.S.) possess railcar units (Ale 80) capable of running on lines equipped with 3 600 V, 16 2/3 c/s

three-phase current supply, and 3 000 V D.C. supply. They consist of a D.C. motor coach and one or more trailers where one of the latter is equipped with pantographs for the collection of three-phase current and with a transformer-rectifier set.

7.2. *Pantographs.*

The pantographs for three-phase current (two catenaries) are of a special type, and their combination with D.C. pantographs is impracticable. It is therefore necessary to mount two additional pantographs.

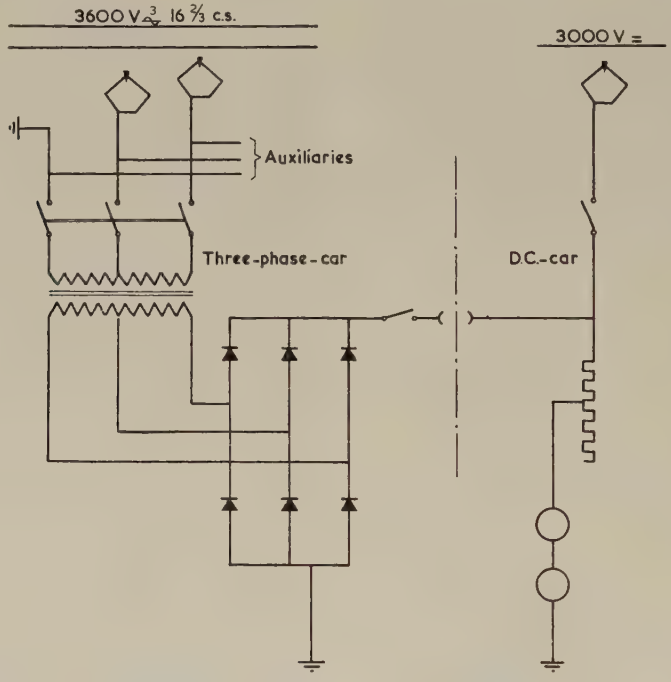


Fig. 11. — Main-circuit of the F.S.-train set for three-phase 3 600 V, 16 2/3 c/s. and 3 000 V D.C.

7.1. *Traction circuit.*

The transformer is of the three-phase type (fig. 11). Rectification is obtained by means of 6 excitrons which are bridge connected. There are no smoothing coils since the three-phase bridge obviates the need for them.

In order to enable a vehicle to work with three-phase current, it is thus necessary to provide a transformer and rectifiers with the corresponding equipment.

7.3. *Auxiliaries.*

On D.C. lines, the current for the motor-compressor-generator set is directly supplied from the catenary. On three-phase lines, the current is obtained through rectifiers.

Some of the auxiliaries are fed with 220 V, others with 24 V.

7.4. *Selection of system.*

The selection of the system is carried out manually.

8. Advantage of the use of multi-current motive power units.

8.1. *Railcars and multiple-unit sets.*

In the case of railcars or multiple unit trains, it is most undesirable to force the passengers to change trains if the through traffic is heavy. The Japanese National Railways, which work a considerable rail-car traffic, reckon with a marked increase in the number of multi-current multiple unit trains.

The German Federal Railways believe that the multi-current multiple-unit trains will play an important part in future international traffic. It will even be necessary for these trains to be equipped for working on current supply systems not immediately adjacent to their home system.

8.2. *Locomotives.*

As far as locomotives are concerned, it may be pointed out that, generally speaking, the multi-current locomotives are always more expensive than those designed to work on a single system only. There is therefore a tendency to avoid their use, and to prefer a change of locomotive where this is possible, and compatible with operating requirements.

The Japanese National Railways point out that locomotive change should be preferred :

a) if traffic is light;

b) if through traffic is comparatively light, and

c) if the changeover station is of small size.

The S.N.C.F. point out that, in general, passenger and goods trains must in any case stop at the transition station, and that this stop can be utilized for the locomotive change.

Such a locomotive change can be carried out at a station where the catenary can be switched over from one current supply to the other.

Another solution consists in entering the other system with the pantograph lowered. When the locomotive has been uncoupled, it must be hauled by a Diesel or steam shunting locomotive back to its own catenary system.

Yet a third solution, which the S.N.C.F. use at Modane, consists in feeding the 1 500 V S.N.C.F. locomotives from a third rail, and the Italian three-phase locomotives from three-phase 3 600 V 16 2/3 c/s catenaries.

The German Federal Railways, moreover, are of the opinion that the construction of locomotives suitable for more than two systems should only be envisaged in exceptional circumstances.

The S.N.C.F. are constructing two types of locomotives suitable for more than one system : one of them able to develop the full power on both systems, and one able to run a full power on the French system and at much reduced power on the adjacent systems. In the latter case, the locomotive will be able to enter the adjacent system beyond the transition point and to start a train from there.

This solution permits a considerable reduction of the additional expenses incurred through the introduction of a second system of electric traction.

The S.N.C.F. are calling such a locomotive a « petit bicourant » or « petit bifréquence » which might be translated as « small-scale dual-current » (or « dual-frequency ») locomotive.

The price of locomotives of the first type, able to develop the full power on the foreign system, is so high that the number of such locomotives is, of necessity, restricted. Their use may become necessary in the case of international trains and luxury express trains in order to avoid the loss of time required for the changing of locomotives.

The S.B.B. possess, at Basle station, six shunting locomotives which can work with 15 kV, 16 2/3 c/s and with 25 kV, 50 c/s.

* * *

The following summaries are proposed as a basis for the discussions at the New Delhi Meeting.

9. Summaries.

1. Multi-current motive power units are power units which can work with more than one type of current.

Such units are already in operation, or under construction, in the following combinations :

(*a*) D.C. systems of different voltages;

(*b*) A.C. systems of different voltages but the same frequency;

(*c*) A.C. systems of different voltages and frequencies;

(*d*) one or more A.C. systems and one or more D.C. systems;

(*e*) one three-phase current system and one D.C. system.

2. Multi-current motive power units for D.C. systems of different voltages are characterized by the following features :

(*a*) Compared with motive power units exclusively designed for the highest voltage concerned :

— there must be a possibility of combining the motors in parallel instead of in series;

— there must be a possibility of connecting the auxiliaries, inasmuch as they are fed from the catenary, in parallel instead of in series, which calls for a division of the auxiliary power;

(*b*) Compared with motive power units exclusively designed for the lowest voltage concerned :

— in addition to the features mentioned under (*a*), it is necessary to provide the traction motors, the high-tension cabling and those auxiliaries fed directly from the catenary with an insulation adequate for the highest voltage.

Only where the highest voltage happens to be a whole multiple of the lowest voltage it is possible to use connection schemes which enable the motive power unit to develop its full power with both voltages.

3. Multi-current motive power units for A.C. systems of different voltages but the same frequency are characterized by the following features :

(*a*) Compared with motive power units exclusively designed for the highest voltage concerned :

— it is necessary to adapt the transformer primary :

— either by dividing the primary winding into groups and connecting these in parallel instead of in series;

— or by means of a tapping on the primary circuit, so arranged that the secondary voltage remains the same.

If it is desired to have the full power available at both voltages, the former method is only applied if the highest voltage is a whole multiple of the lowest voltage. With the second method, on the other hand, it is always possible to obtain the desired tapping provided that the primary windings are suitably reinforced.

Moreover, the second method permits of speed regulation on the high-tension side;

(*b*) Compared with motive power units exclusively designed for the lowest voltage concerned :

— in addition to the features mentioned under (*a*), it is necessary to provide the transformer primary, the pantographs, the pneumatic circuit breaker and the cabling between these components with an insulation adequate for the highest voltage.

4. Multi-current motive power units for A.C. systems of different voltages and frequencies may be equipped :

(a) either with A.C. motors;

(b) or with undulating current motors.

In the latter case, it is necessary to increase the size of the transformer, to an extent which depends on the rectifier connection scheme. Though more complicated, and not normally used on low-frequency motive power units designed for one type of current only, this solution is still the one most commonly adopted if the motive power unit must also work with A.C. of higher frequency.

In the former case (A.C. motors), the multi-current motive power units are characterized by the following features :

(a) (1) Compared with motive power units exclusively designed for the highest voltage and frequency concerned, it is necessary :

— to enlarge the copper cross-section of the primary transformer windings;

— to enlarge the section of the magnetic core;

— to provide for the possibility of modifying the degree of interpole shunting;

— to provide switch-over facilities for the tertiary transformer winding, used for current supply to the auxiliaries;

(a) (2) Compared with motive power units exclusively designed for the lowest voltage and frequency concerned, it is necessary :

— to insulate the transformer primary for the highest voltage;

— to subdivide the transformer windings to a greater extent in order to reduce the leakage at the highest frequency;

— to provide for the possibility of modifying the degree of interpole shunting;

— to provide switch-over facilities for the tertiary transformer winding.

In the second case (undulating current motors), the multi-current motive power units are characterized by the following features :

(b) (1) Compared with motive power units exclusively designed for the highest voltage and frequency concerned, it is necessary :

— to enlarge the copper cross-section of the primary transformer windings;

— to enlarge the section of the magnetic core;

— to adapt the rectifier ignition coils for the lowest frequency;

— to provide switch-over facilities for the tertiary transformer winding;

(b) (2) Compared with motive power units exclusively designed for the lowest voltage and frequency concerned (and equipped with A.C. traction motors) :

— in addition to the features listed under (a) (2) above;

— traction motors for undulating current are most commonly used.

5. Multi-current motive power units for one or more A.C. systems and one or more D.C. systems are always equipped with rectifiers.

The speed can be controlled :

— on the A.C. side;

— on the D.C. side;

— at the rectifiers, if these are equipped with grids.

Speed regulation on the A.C. side or at the rectifiers gives rise to additional complication of the equipment. D.C. regulation increases the cost of energy consumed.

Multi-current motive power units of this category are characterized by the following features :

(*a*) Compared with motive power units exclusively designed for A.C. of the highest voltage and frequency concerned :

— in addition to the features listed under (*b*) (1) of Summary No. 4, it is necessary :

— to adopt construction devices permitting current collection (for the stationary train as well as the running train) and speed regulation on D.C. lines;

— to use D.C. traction motors which, being insulated for the highest D.C. voltage to be taken into account, must be heavier than with A.C. motors;

— to install appropriate circuit breakers and starting resistances equipped with the necessary contactors;

— to use auxiliaries which, inasmuch as they are also required for D.C. working, must be designed for D.C. and must, on A.C. lines, be fed through rectifiers.

The elimination of speed control on the A.C. side or at the rectifiers may also be envisaged.

(*b*) Compared with motive power units exclusively designed for A.C. of the lowest voltage and frequency concerned, it is necessary :

— to resort to rectifier equipment, as the possibility of designing motive power units capable of working on 1 500 V D.C. lines with motors also suited for A.C. feed is merely academic;

— to enlarge the size of the transformer, as mentioned in Summary No. 4.

In addition, when working on D.C. lines, these motive power units must have the same features as under (*a*) above;

(*c*) Compared with motive power units exclusively designed for D.C. of the highest voltage concerned, it is necessary :

— when working on D.C. lines, to rely on the same measures as those listed in Summary No. 2, letter (*a*);

— when working on A.C. lines, to install a transformer, an air circuit breaker and rectifiers to feed the traction circuits and auxiliaries;

(*d*) Compared with motive power units exclusively designed for D.C. of the lowest voltage concerned, it is necessary :

— when working on D.C. lines, to rely on the same measures as those listed in Summary No. 2, letter (*b*);

— when working on A.C. lines, to rely on the same measures as those listed under (*c*) above.

6. In the only reported case of D.C. motive power units being adapted to working with three-phase current, a three-phase transformer and rectifiers have been provided to feed the traction motors and auxiliaries when working on A.C. lines.

7. To enable motive power units to work on lines with different types of current, they may have to be equipped with one or more additional pantographs, depending on the networks on which they are to run, unless the dimensions of the collector bow can be completely standardized.

8. It is desirable to provide, on multi-curent motive power units, either a protection device preventing the wrong choice of system, or a wholly automatic system selection device.

9. In all cases, where it is not necessary to obtain the full power with all the types of current concerned, the various conditions outlined above may be relaxed or even ignored, and other solutions might also be adopted.

10. It is less difficult to base the design of a multi-current motive power unit on that of a unit designed for the highest voltage and frequency concerned, than on the design of a unit designed for the lowest voltage and frequency concerned, or for D.C.

11. Multi-current motive power units are more complicated, and therefore more costly, than motive power units designed for one type of current only.

The application of such units is therefore reduced as much as possible.

In consequence, the numbers of such vehicles for which orders are placed are comparatively small, and this fact tends to increase the price still further.

12. Owing to their complexity, the cost of maintaining the electrical parts of multi-current motive power units is higher than with units designed for one type of current only. This applies the more, the greater the number of different types of current for which the unit is designed.

However, as the total maintenance cost is largely governed by the maintenance of the mechanical parts, an increase in the cost of maintaining the electrical parts will not have a major incidence on the total maintenance cost.

13. In view of the fact that the first cost and maintenance cost of multi-current motive power units are higher than those of units designed for one type of current only, preference should be given to the alternative solution of changing locomotives at the transition station, wherever this solution is compatible with operating conditions.

14. Where the change of motive power units is not compatible with operating conditions, e.g. because :

— the transition stations would become too complicated, or

— it is desired to work through trains without changing locomotives, or

— it is desired to obviate the need for passengers to change from one railcar or multiple-unit train to another, or

— it is necessary to have regard to the shunting movements at stations equipped for more than one type of current;

multi-current motive power units must be used.

The technical feasibility is demonstrated by vehicles already in service.

15. If operating requirements permits, it is advisable, for economic reasons, to design the multi-current motive power units, with one type of current, working at reduced power.

This solution is acceptable if the working of the motive power units is confined to short runs to and from the transition stations to reach the station of the adjoining railway system equipped with one type of current only.

[656 .223 .2]

A method to calculate the circulation and round-trip times of wagons in railway regions,

by Professor Dr. Wladyslaw Wyrzykowski, Warsaw.

I. Vectorial conception of the movement structure in the region.

It is proposed to consider a region S of a railway network (fig. 1), which may represent an administrative district or region, or even a self-contained railway administration (which will generally cover the whole of a country).

This region S may contain railway lines with different sections and stations of any number or configuration, and with any kind of links between the lines inside and outside the region.

The lines and stations of region S may have to deal with any number of different wagon trips and shunting movements. The configuration of the vectors, representing the resultants of wagon traffic flows in all possible combinations within the region, is shown in figure 1. This vectorial configuration has the following features :

1. Each vector represents the resultant of the elementary flows of all (or of the great majority of) wagons of a given category of traffic within region S. Magnitude and direction of the symbolic vectors, graphically shown in figure 1, have no bearing on the problem here discussed. In contrast, the orientation of these vectors as well as the location of their beginning and end in relation to the regional boundary has a vital significance.

2. The term « *transit wagons* » will be used to denote those wagons which pass through region S either loaded or empty, being loaded and unloaded outside the boundaries of the region. That is why vector AB, which represents the flow of loaded transit wagons passing through region S, as a resultant of all the elementary flows of wagons of this kind passing over the different lines of region S, has its origin at point A of figure 1, symbolically denoting the point where these wagons are loaded, and its end at point B, symbolically denoting the point where they are unloaded. Points A and B are therefore outside the boundaries of region S.

The tip of the vector expresses the direction of the wagon movement, the notation U_{tch} shown above the vector denotes the approximate volume of the traffic flow, expressed in numbers of wagons per 24 hours. Points *a* and *b* signify the resultants of the arrival and departure points of the flows of wagons of this category in the region, whilst section *ab* of vector AB denotes, symbolically, the route of loaded transit wagons passing through region S.

Similarly, vector CD represents the resultant flow of empty transit wagons passing through region S (the mean volume being U_{tv} wagons per day).

3. By « *incoming traffic* » is meant both the number of loaded wagons which were

loaded outside the region and are unloaded inside the region, and the number of empty wagons which arrive from outside and are loaded inside the region.

From figure 1, it is obvious that vector EF which denotes, symbolically, the empty incoming wagons, having a mean volume of U_{iv} wagons per day, and bifurcating towards two of the possible symbolic loading points within region S, viz. K and M, is represented in figure 1 by the resultant vector GH and the

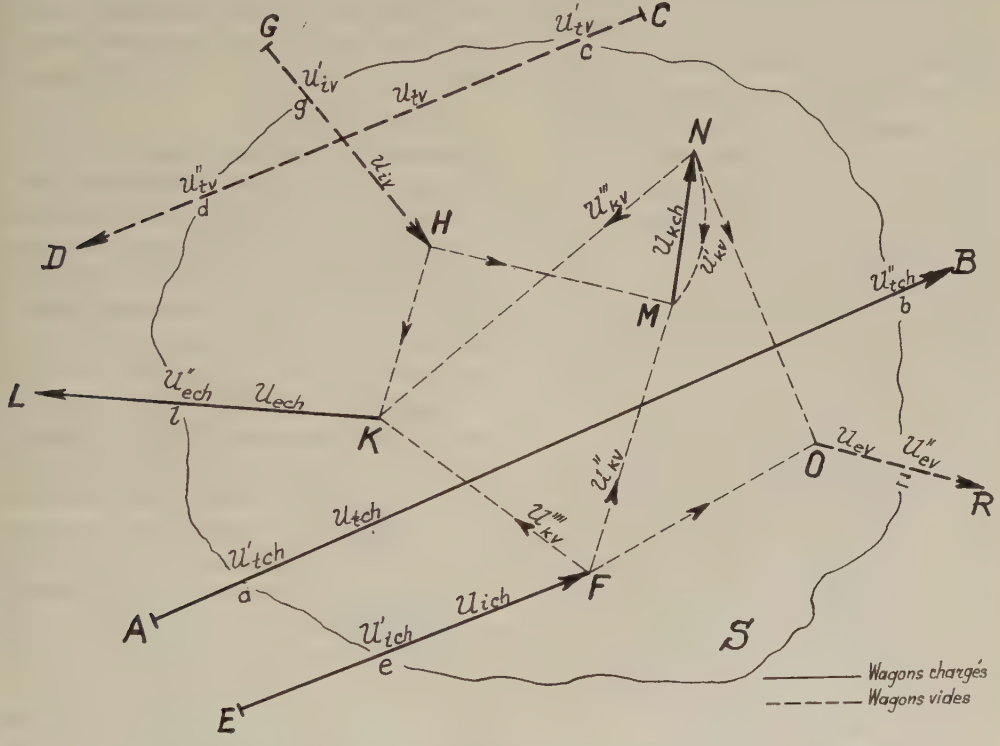


Fig. No. 1.

N. B. — Wagons chargés = loaded wagons. — Wagons vides = empty wagons.

traffic of loaded wagons entering the region at a mean flow of U_{ich} wagons per day, originates at point E, symbolically denoting the loading point of the wagons outside region S, and ends at point F, symbolically denoting the unloading point of the wagons inside region S. The section *e*F of vector EF denotes that part of the trip of the loaded incoming wagons which is inside the region. The flow of constituent vectors, HM and HK; the sections *g*H, HM and HK represent the symbolic routes of empty incoming wagons.

Each loaded incoming wagon goes, within the region S, through a loading process and is included in this traffic category from the moment when the wagon enters the region to the moment when it departs from the unloading

station. Incoming empty wagons are not subjected, within region S, to loading and unloading operations, and are not included in this traffic category until they arrive at the loading station.

4. By « *outgoing traffic* » are meant both loaded wagons which, after being loaded in the region S, leave the region for unloading elsewhere, and empty wagons departing from the unloading station within the region, and leaving the region.

Under these conditions, the flow of loaded outgoing wagons, with a mean volume of U_{ech} wagons per day, is represented in figure 1 by the vector KL, where K denotes, symbolically the loading point for outgoing wagons, and the section K*l* denotes the route taken by these wagons inside region S.

The flow of empty outgoing wagons, with a mean volume of U_{ev} wagons per day, is represented in figure 1 by the resultant vector OR and its constituent vectors FO and NO, where the points F and N are regarded as symbolic unloading points (the only ones possible in the region). These points F and N are therefore the only points from which flows of empty wagons can emanate (1).

The sections FO, NO and OR denote the symbolic routes of empty outgoing wagons.

Every outgoing loaded wagon goes through a loading process within region S and is treated as being part of the outgoing traffic flow from the moment when the empty wagon arrives at the loading station, to the moment when the wagon passes through point *l* at the boundary of region S.

Empty outgoing wagons do not undergo any loading or unloading operations within the region and are included in this traffic category from the moment when the wagon leaves the unloading station to the moment when the wagon passes the boundary of region S, at point *z*.

5. Finally, the term « *local* (*traffic*) *wagons* » is used for wagons which go through two operations in region S, viz. a loading operation as well as an unloading operation, and for wagons which, after having been unloaded at a station within region S, are despatched as empty wagons, to another station in the same region to be loaded there.

The flow of loaded wagons in local traffic, with the mean volume of U_{kch} wagons per day, is represented in figure 1 by the vector MN, where M represents the symbolic loading point of local wagons, whilst N denotes the unloading point. The section MN denotes, symbolically, the route covered by loaded local wagons within the region S.

The flows of empty wagons in local traffic, with a mean volume of U_{kv} wagons per day, are symbolized by four vectors : NM, FM, FK and NK, representing four constituent flows of such wagons, the only ones possible in the region. The sections NM, FM, FK and NK symbolize the routes covered by empty local wagons within the region S.

Each wagon belonging to the flow of loaded local wagons goes through two operations within the region (viz. loading and unloading), and forms part of this local traffic from the moment when the empty wagon arrives at the loading

(1) On the assumption that incoming empty wagons must not directly, as empty wagons, join the flow of outgoing wagons.

station to the moment when the empty wagon departs from the unloading station (1).

The empty local wagons do not undergo any loading operation and are included in this traffic category from the moment at which they leave the unloading station to the moment at which they arrive at the loading station.

6. While the wagon remains in the region (forming part, during that time, of a given traffic category), each wagon is engaged in movements or in loading or shunting operations. These movements and operations represent the constituent phases and occur in cycles.

A cycle of phases, e.g. of loaded local wagons, will consist of two loading operations, line movements and possibly shunting. As far as empty local wagons are concerned, the cycle will merely consist of line movements and, possibly, shunting movements. Loaded incoming and outgoing wagons have a working cycle consisting of a loading phase, a line movement phase, and possibly a shunting phase.

In these six paragraphs, a conception has been outlined where all the movements in the region are conceived in vectorial form, a conception comprising the trips as well as the work performed by the wagons in all possible traffic categories. Although certain assumptions made in these six paragraphs may be somewhat arbitrary (e.g. the allocation of loading operations to certain categories of traffic) the vectorial conception of the movements within the region, inherent in all these assumptions, will be useful in conjunction with the following considerations which will permit the determination of some of the rules governing the movement of wagons in the region.

We shall adopt the following symbols :

— Number of loaded transit wagons entering the region in 24 hours U'_{tch} wagons per day.

— Number of loaded transit wagons leaving the region in 24 hours U''_{tch} wagons per day.

— Number of empty transit wagons entering the region in 24 hours U'_{tv} wagons per day.

— Number of empty transit wagons leaving the region in 24 hours U''_{tv} wagons per day.

— Number of loaded incoming wagons entering the region in 24 hours U'_{ich} wagons per day.

— Number of empty incoming wagons entering the region in 24 hours U'_{iv} wagons per day.

— Number of loaded outgoing wagons leaving the region in 24 hours U''_{ech} wagons per day.

— Number of empty outgoing wagons leaving the region in 24 hours U''_{ev} wagons per day.

These values are indicated in figure 1 at the side of the symbolic points at which the boundaries of region S are crossed.

We shall also use the following notations :

U_{ch} — the total number of loaded wagons in the region in 24 hours;

(1) In the case of double loading operation at the loading station, or at the unloading station : from the half-time point between the moment at which the wagon is finally unloaded, and the moment at which the new loading commences.

U_{chk} — the number of loaded local wagons in the region in 24 hours;

U_{che} — the number of loaded outgoing wagons in the region in 24 hours;

U_{d} — the total number of wagons unloaded in the region in 24 hours;

U_{dk} — the number of local wagons unloaded in the region in 24 hours;

U_{di} — the number of incoming wagons unloaded in the region in 24 hours.

It is obvious that

$$U_{ch} = U_{chk} + U_{che} \quad (1)$$

$$U_{d} = U_{dk} + U_{di} \quad (2)$$

II. Conception of the stabilised movement of wagons in the region.

The movement of the wagons of any traffic category, expressed by the vector in accordance with the conception here adopted, will be stabilized for a period of time il the number of wagons entering this category during this period, at the origin of the vector, is equal to the number of wagons leaving the category, at the tip of the vector.

In accordance with this definition, the entrance and departure of the wagons must be taken to relate to the railway network of the region analyzed so that, for the transit, outgoing and incoming traffic categories it is necessary to regard the corresponding vectors as originating or ending at the boundary of the region. For instance, the origin of the vector AB must be taken at point *a* and its end at point *b* of figure 1; the origin of vector EF at point *e*, the end of vector KL at point *l*, etc.

The wagon movements of the different categories of traffic will then be stabilized if

— in loaded transit traffic :

$$U'_{tch} = U''_{tch} \quad (3)$$

— in empty transit traffic :

$$U'_{tv} = U''_{tv} \quad (4)$$

— in loaded incoming traffic :

$$U'_{ich} = U_{di} \quad (5)$$

— in loaded outgoing traffic :

$$U_{che} = U''_{ech} \quad (6)$$

— in loaded local traffic

$$U_{chk} = U_{dk} \quad (7)$$

— in the combined incoming, outgoing and local traffic of empty wagons :

$$U'_{iv} - U''_{ev} = U_{ch} - U_{d} \quad (8)$$

Reverting to the conception of the mean volume of wagon traffic flows mentioned above, it is possible to modify the above equations by defining the criteria of stabilized movement as follows:

$$U'_{tch} = U''_{tch} = U_{tch} \quad (9)$$

$$U'_{tv} = U''_{tv} = U_{tv} \quad (10)$$

$$U'_{ich} = U_{di} = U_{ich} \quad (11)$$

$$U_{che} = U''_{ech} = U_{ech} \quad (12)$$

$$U_{chk} = U_{dk} = U_{kch} \quad (13)$$

$$U'_{iv} - U''_{ev} = U_{ch} - U_{d} = U_{iv} - U_{ev} \quad (14)$$

If equations (3) to (8) apply, the movement of the wagons in the corresponding traffic categories is stabilized, and the volume can be calculated by using equations (9) to (14). If, on the other hand, any of the equations (3) to (7) does not apply, the movement of wagons in the corresponding categories is not stabilized so that the number of wagons in the region may increase or decrease.

During periods when the movement of wagons in the region is not stabilized, the mean volumes of the flows can be approximately worked out in the following way :

$$U_{tch} = \frac{U'_{tch} + U''_{tch}}{2} \text{ wag./day} \quad (15)$$

$$U_{tv} = \frac{U'_{tv} + U''_{tv}}{2} \text{ wag./day} \quad (16)$$

$$U_{ich} = \frac{U'_{ich} + U_{di}}{2} \text{ wag./day} \quad (17)$$

$$U_{ech} = \frac{U_{che} + U''_{ech}}{2} \text{ wag./day} \quad (18)$$

$$U_{kch} = \frac{U_{chk} + U_{dk}}{2} \text{ wag./day} \quad (19)$$

It is necessary to ascertain the numerical values of the terms U'_{tch}, U''_{tch}, U'_{tv}, U''_{tv}, U'_{ich}, U''_{ech}, U'_{iv} and U''_{ev} at the re-forwarding and reception stations of the region, either per 24 hours or per week, and then to work out the mean values per day.

The numerical values of the terms U_{di}, U_{dk}, U_{che} and U_{chk} must be determined at the loading stations and must be calculated in the same way as the preceding values.

Equations (3) to (8) can serve as a control for the actual movement of goods traffic in the region, and it is possible, with their aid, to determine the causes of an excessive accumulation of wagons in the region.

III. The wagon trip times in the region.

Each wagon which, while remaining in the region, belongs to a given category of traffic, passes through the working cycle typical for that category, which consists of different phases, viz. trips, shunting and loading operations. The duration of each phase of this cycle is given. For each category of traffic, the aggregate time of the constituent phases of the cycle represents the time during which the wagon remains in the region, and the product of this time, as related to the mean wagon of this traffic, multiplied by the mean volume of this traffic category, represents the desired total number of wagons in the traffic category concerned.

The trip times and operation times of the wagons in the traffic categories concerned can be expressed as follows, taking into account the cycle with the three constituent phases already mentioned :

$$T_{tch} = \frac{1}{24 \cdot U_{tch}} \left[\frac{\Sigma(ns)_{tch}}{V_h} + U_{rtch} \cdot t_r \right] \text{ (days)} \quad (20)$$

$$T_{tv} = \frac{1}{24 \cdot U_{tv}} \left[\frac{\Sigma (ns)_{tv}}{V_h} + U_{rtv} \cdot t_r \right] \text{ (days)} \quad (21)$$

$$T_{ich} = \frac{1}{24} \left\{ t_o + \frac{1}{U_{ich}} \left[\frac{\Sigma(ns)_{ich}}{V_h} + U_{rich} \cdot t_r \right] \right\} \text{ (days)} \quad (22)$$

$$T_{ech} = \frac{1}{24} \left\{ t_o + \frac{1}{U_{ech}} \left[\frac{\Sigma(ns)_{ech}}{V_h} + U_{rech} \cdot t_r \right] \right\} \text{ (days)} \quad (23)$$

$$T_{kch} = \frac{1}{24} \left\{ 2 \cdot t_o + \frac{1}{U_{kch}} \left[\frac{\Sigma (ns)_{kch}}{V_h} + U_{rkch} \cdot t_r \right] \right\} \text{ (days)} \quad (24)$$

The variables used in equations (20) to (24) have the following significance :

$\Sigma(ns)_{tch}$ — the loaded transit traffic in terms of wagon-km per 24 hours within the region;

$\Sigma(ns)_{tv}$ — the empty transit traffic in terms of wagon-km per 24 hours within the region;

$\Sigma(ns)_{ich}$ — the loaded incoming traffic in terms of wagon-km per 24 hours within the region;

$\Sigma(ns)_{ech}$ — the loaded outgoing traffic in terms of wagon-km per 24 hours within the region;

$\Sigma(ns)_{kch}$ — the loaded local traffic in terms of wagon-km per 24 hours within the region;

V_h — the average commercial speed of the goods trains running in the region;

U_{rtch} — the number of loaded transit wagons which are being shunted and handled in 24 hours at all the marshalling yards of the region;

U_{rtv} — the number of empty transit wagons which undergo the same operations;

U_{rich} — the number of loaded incoming wagons which undergo the same operations;

U_{rech} — the number of loaded outgoing wagons which undergo the same operations;

U_{rkch} — the number of loaded local wagons which undergo the same operations;

t_o — the average time (in hours) during which a wagon remains at a loading or unloading station (representative of average conditions);

t_r — the average time (in hours) during which a wagon remains in a marshalling yard (representative of average conditions);

U_{tch}, U_{tv}, U_{ich}, U_{ech} and U_{kch} — as explained earlier on.

IV. Number of wagons within the region.

By using the above equations, the number of wagons within the region can be calculated as follows :

— Loaded transit wagons :

$$N_{tch} = T_{tch} \cdot U_{tch} \text{ [wag.]} \quad (25)$$

— Empty transit wagons :

$$N_{tv} = T_{tv} \cdot U_{tv} \text{ [wag.]} \quad (26)$$

— Loaded incoming wagons :

$$N_{ich} = T_{ich} \cdot U_{ich} \text{ [wag.]} \quad (27)$$

— Loaded outgoing wagons :

$$N_{ech} = T_{ech} \cdot U_{ech} \text{ [wag.]} \quad (28)$$

— Loaded local wagons :

$$N_{kch} = T_{kch} \cdot U_{kch} \text{ [wag.]} \quad (29)$$

Equations (25) to (29) can be used for the calculation of the standard numbers of wagons in the different traffic categories in the region, when the values T have been calculated from formulas (20) to (24). In these formulas, the variables t_o and t_r are given by the diagrams of elementary working operations at the stations; V_h from the graphs of the train movements, and the remaining variables from the diagrams showing the composition and routes of the trains.

Equations (20) to (29) may also be used for operating purposes. In that case, however, the variables of these equations will be determined either by statistics or by censuses carried out in the region.

It is possible to determine, for a region, the actual numbers of wagons for a period of time, either by calculating the wagons on the spot, or on the strength of the known number of wagons for the preceding period of time, taking into account the differences in the total numbers produced in the interval between these two periods of time.

The calculation of the numbers of wagons must then be based on the following equations :

$$N_{tch} = N^{o}_{tch} + U'_{tch} - U''_{tch} \text{ [wag.]} \quad (30)$$

$$N_{tv} = N^{o}_{tv} + U'_{tv} - U''_{tv} \text{ [wag.]} \quad (31)$$

$$N_{ich} = N^{o}_{ich} + U'_{ich} - U_{di} \text{ [wag.]} \quad (32)$$

$$N_{ech} = N^{o}_{ech} + U_{che} - U''_{ech} \text{ [wag.]} \quad (33)$$

$$N_{kch} = N^{o}_{kch} + U_{chk} - U_{dk} \text{ [wag.]} \quad (34)$$

$$N_{qv} = N^{o}_{qv} + U'_{tv} - U''_{ev} + U_{d} - U_{ch} \text{ [wag.]} \quad (35)$$

In these equations, the variables N^{o}_{tch}, N^{o}_{tv}, N^{o}_{ich}, N^{o}_{ech}, N^{o}_{kch} et N^{o}_{qv} denote the numbers of wagons in the preceding period, whilst the symbol N_{qv} expresses the total actual number of empty incoming, outgoing and local wagons.

The remaining variables in equations (30) to (35) must be ascertained from the censuses referred to above.

The total number of wagons, N, in the region can, of course, be calculated from the following formula :

$$N = N_{tch} + N_{tv} + N_{ich} + N_{ech} + N_{kch} + N_{qv} \text{ [wag.]} \quad (36)$$

and the total number of loaded wagons (N_{ch}) in the region from the equation :

$$N_{ch} = N_{tch} + N_{ich} + N_{ech} + N_{kch} \text{ [wag.]} \quad (37)$$

Finally, the number of empty wagons in the region can be calculated from the equation

$$N_{v} = N_{tv} + N_{qv} \text{ [wag.]} \quad (38)$$

For certain calculations concerning the wagon round-trip time in the region, it will be necessary to make use of the total numbers of loaded outgoing, incoming and local wagons, calculated as follows :

$$N_{qch} = N_{ich} + N_{ech} + N_{kch} \text{ [wag.]} \quad (39)$$

or :

$$N_{qch} = N^{o}_{qch} + U'_{ich} + U_{ch} - U_{d} - U''_{ech} \text{ [wag.]} \quad (40)$$

One may even require the total number of loaded and empty wagons in incoming, outgoing and local traffic, which can be calculated from the equation :

$$N_{q} = N_{qch} + N_{qv} \text{ [wag.]} \quad (41)$$

With the aid of all these equations, it is possible to determine the numbers of wagons in the region. These equations, or at least some of them, can be used directly in operating practice. They will also be used in the following Chapter of our study which deals with the wagon round-trip time.

V. Wagon round-trip time.

According to the explanation given at the beginning of Chapter III, the degree of utilisation, within the region, of the wagons in the different traffic categories in relation to time can be calculated from that part of the time (T) spent within the region, during which the wagons are employed in a working cycle consisting of trips, shunting and loading operations.

The standard times (T) can be determined from equations (20) to (24) and, as far as the operating times are concerned, the duration of the actual times (T) can be determined from equations (25) to (29) as the quotients of the numbers of wagons and the mean volumes of the corresponding traffics. From the result, a precise knowledge of the degree of utilisation of the wagons in the region in relation to time can be obtained, separately for each traffic category. We shall now examine the unit of measurement (and its mathematical expression), for the utilisation, related to time, of all the wagons in the region, on the strength of the definition of this unit as the quotient of the number of wagons and the volume of wagon flows.

It is certainly not possible to find a simple mathematical formula for this unit (T.) as the quotient of the total number of wagons in the region and the sum of the volumes of wagons in all combinations, since the working cycles of the wagons in the region, which relate to different categories of traffic, have different phases. For example, transit wagons do not undergo any loading operation; local wagons pass through two operations, and incoming and outgoing wagons pass through one. In consequence, the measuring indices thus defined vary with the proportion of the different categories of traffic comprised in the total traffic.

That is why we shall adopt the following approach : In considering the total number of wagons (N) as potential value of N wagon-days, which are capable of working in the region, 24 N wagon-hours in 24 hours, and placing it into the numerator of the mathematical formula required, we place into the denominator the number of cycles performed by the wagons in the region during 24 hours, as mentioned in paragraph 6 of Chapter I.

However, all the wagons comprised in the total number of wagons forming the numerator are liable to undergo modification in respect of the nature and length of the phases of the working cycles. It is therefore necessary to subtract the loaded and empty transit wagons and to find, for the remaining wagons, the mathematical form of the required denominator. This can be done in the following way :

The cycle is assumed to consist of six phases, viz. the loading of the wagons, the transport of the loaded wagons to the unloading station, the shunting and handling of the same wagons at the marshalling yards in the region in the course of this transport, the unloading of the wagons, the transport of the empty wagons to the new loading stations, and finally the shunting and handling of the empty wagons in the marshalling yards. In this way, we obtain a normal wagon round-trip cycle. The loaded local wagons go through a working cycle which differs from the one outlined above by the absence of phases concerned with the empty wagons; the loaded outgoing and

incoming wagons differ inasmuch as one loading operation and the empty wagon phases are missing. On the other hand, the empty local, incoming and outgoing wagons merely pass through the phases envisaged for the empty wagons, and circulate in the region exclusively for the purpose of ensuring their loading (cf. figure 1).

It is precisely the empty wagons going through those phases which are missing in the otherwise complete cycle of loaded wagons in the first three traffic categories therefore, even these must be analyzed together.

By hypothetically combining, in the following, the movements of loaded outgoing and incoming wagons in groups, one obtains for such groups cycles with the same number of phases (viz. two loading operations per wagon) as for loaded local wagons.

We thus obtain cycles with phases which are similar in the sense that the loaded incoming and outgoing wagons form groups whilst the empty wagons in the three mentioned traffic categories complete the missing phases of the loaded incoming, outgoing and local wagons.

Each cycle thus obtained includes a loading phase as well as an unloading phase. In consequence, the number of such cycles performed in the region within 24 hours is equal to

$$\frac{U_{ch} + U_d}{2}$$

and this value must become the denominator of the mathematical formula required. By adopting for this formula the symbol W, we can write :

$$W = \frac{2 \cdot Nq}{U_{ch} + U_d} \quad \text{(days)} \qquad (42)$$

where N_q can be obtained from equations (41), (35) and (40).

The unit of measurement, W, expresses the duration of a mean working cycle of the wagons in the region, and in connection with this analysis, this cycle expresses the round-trip time of the wagons. It is, however, only this unit of measurement W, expressing the utilisation time of the loaded and empty wagons, which concerns the outgoing, incoming and local traffics, whilst the unit of measurement of loaded and empty transit wagons is expressed by the time (T) indicated by equations (25) and (26). That is why, in our opinion, it is necessary to use the three equations (42), (25) and (26) for the operating calculation of the degree of utilisation of the wagons in a given time, where the transit traffic flows are important and their volume variable.

The formula obtained (42) is a new one.

Other formulas concerning the wagon round-trip time are known, and are often applied in railway practice. The best-known among them are :

$$W = \frac{N}{U_{ch}} \quad \text{(days)} \qquad (43)$$

$$W = \frac{N}{U_{ch} + U_{tch} + U_{ich}} \quad \text{(days)} \qquad (44)$$

$$W = \frac{N}{U_{ch} + U_{ich} - U_{ech}} \quad \text{(days)} \qquad (45)$$

$$W = \frac{N}{U_{ch} + \frac{U_{ich} - U_{ech}}{2}} \quad \text{(days)} \qquad (46)$$

The significance of the variables used in equations (43) to (46) has already been explained.

All these equations, (43) to (46), have the same drawback, viz. they include in the numerator the total number of wagons in all the traffic categories, including transit traffic.

Moreover, the denominators of equations (44) and (45) express neither the overall volume of the constituent traffic categories with the same working phases, nor even the number of given cycles. The only correct denominator is that of equation (46), because :

$$U_{ch} + \frac{U_{ich} - U_{ech}}{2} = \frac{U_{ch} + U_d}{2}.$$

If the reciprocal proportion of the volumes of the flow of transit wagons and those of the flow of wagons in all the other traffic categories is modified, one obtains, with equations (43) to (46), different results although, in reality, the round-trip time of the wagons remains the same.

We shall now slightly modify equation (42) in order to eliminate the number of empty transit wagons which is, in practice particularly difficult to ascertain.

From equations (36), (39) and (41), one obtains

$$N = N_{tch} + N_{tv} + N_q$$

and, by introducing this value of N into formula (42), the following equation :

$$W = \frac{2(N - N_{tch} - N_{tv})}{U_{ch} + U_d} \text{ (days)} \qquad (47)$$

By writing :

$$\frac{T_{tv}}{W} = C \qquad (48)$$

and since, according to equation (26),

$$N_{tv} = T_{tv} \cdot U_{tv}$$

one obtains

$$N_{tv} = W \cdot C \cdot U_{tv} \qquad (49)$$

By introducing the value N_{tv} furnished by equation (49) into equation (47), one obtains :

$$W = \frac{2(N - N_{tch} - C \cdot W \cdot U_{tv})}{U_{ch} + U_d},$$

and, after certain modifications :

$$W = \frac{2(N - N_{tch})}{U_{ch} + U_d + 2 \cdot C \cdot U_{tv}} \text{ (days)} \qquad (50)$$

Equation (50) is a wanted variant of equation (42); but it contains a parameter C which calls for the following explanation :

As equation (48) shows, the parameter C is the quotient of the mean running time T_{tv} of empty transit wagons across the region, and of the round-trip time in this region of all the wagons other than the transit wagons. The time T_{tv} is calculated from equation (21) given above, whilst the time W can be determined from the equation :

$$W = \frac{1}{12}\left\{t_o + \frac{1}{U_{ch} + U_d}\left[\frac{\Sigma(ns)_q}{V_h} + U_r \cdot t_r\right]\right\} \text{ (days)} \qquad (51)$$

where

$\Sigma(ns)_q$ = the traffic, in wagon-km per 24 hours, in the region, of the loaded and empty incoming, outgoing and local wagons.

U_r = the number of loaded and empty incoming, outgoing and local wagons shunted and handled in all the marshalling yards of the region in 24 hours.

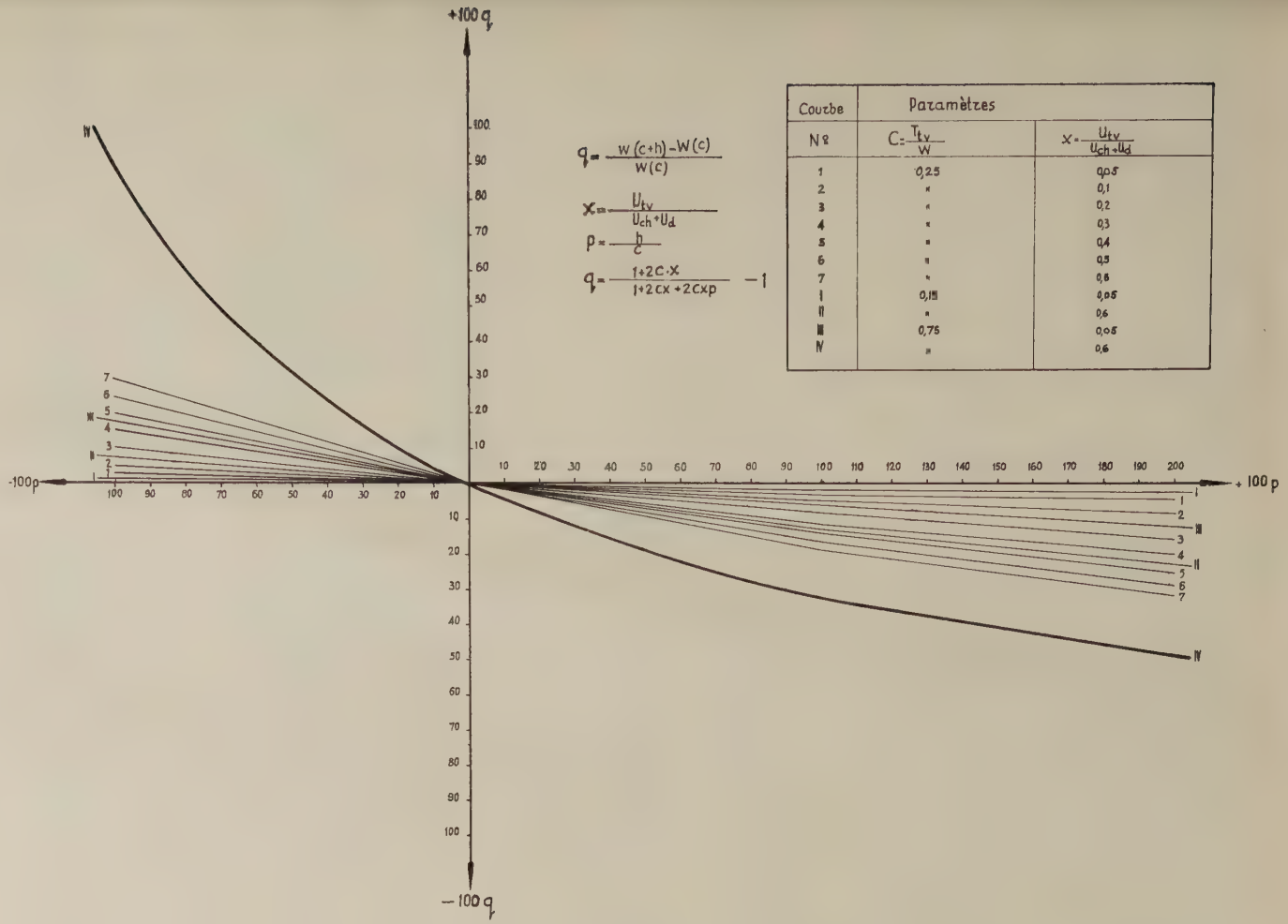


Fig. No. 2.

N. B. — Courbe = curve. — Paramètres = parameters.

t_o, U_{th}, $U_{\bar{d}}$, V_h and t_r have been referred to above.

It can be assumed that, in practice, the need for thus re-calculating the parameter C will only occur if there are marked fluctuations in the configuration of traffic in the region. Moreover, according to figure 2 (1), the relationship established by equation (50) between the wagon round-trip W and the parameter C is such that even very important modifications, attaining some tens of percent, of the parameter C, will only cause slight changes in the round-trip time W, of the order of magnitude of a few per cent.

Research carried out by the author on the Polish railway system has shown that — as far as the Railway region with the greatest transit traffic is concerned, where the proportion of the flow volumes of empty transit wagons, U_{tv}, and the term $U_{ch} + U_{\bar{d}}$ was found to be 0.6 — the relationship between the changes of the values of W and C is that represented by curve NII. This curve can be regarded as being placed in the least favourable position. But even for this curve, a modification of the C value by 50 per cent. will cause a modification of the W value of no more than 10 per cent.

VI. **Conclusions.**

From the foregoing considerations, it would appear possible to formulate the following conclusions which are designed to permit a rationalisation of railway transport methods.

1. In practice, it is possible to make use of the equations and formulas developed in the preceding chapters, viz.

a) equation (3) to (8) — in order to ascertain whether the movement of wagons in the region is stabilized;

b) equations (30) to (41) — in order to calculate the numbers of wagons;

c) formulas (25) and (26) — in order to calculate the time taken by transit wagons to pass through the region;

---

(1) The curves in figure 2 are plotted as follows : If h denotes the modification of the absolute value of the parameter C, and p the change in the relative value of the parameter C, i.e.

$$p = \frac{h}{C},$$

the relative change q of the wagon round-trip time W can be calculated from

$$q = \frac{W/C + h/ - W/C/}{W/C/} = \frac{W/C + h/}{W/C/} - 1$$

Now, by introducing into this equation the mathematical function W and C expressed by equation (50), one obtains

$$q = \frac{U_{ch} + U_{\bar{d}} + 2\,C\,U_{tv}}{U_{ch} + U_{\bar{d}} + 2\,C \cdot U_{tv} + 2 \cdot h \cdot U_{tv}} - 1$$

or

$$q = \frac{1 + 2 \cdot C \dfrac{U_{tv}}{U_{ch} + U_{\bar{d}}}}{1 + 2 \cdot C \dfrac{U_{tv}}{U_{ch} + U_{\bar{d}}} + 2\,C \dfrac{U_{tv}}{U_{ch} + U_{\bar{d}}} \cdot \dfrac{h}{C}} - 1$$

By substituting :

$$x = \frac{U_{tv}}{U_{ch} + U_{\bar{d}}} \quad \text{and} \quad p = \frac{h}{C}$$

one finally obtains :

$$q = \frac{1 + 2 \cdot C \cdot x}{1 + 2 \cdot C \cdot x + 2 \cdot C \cdot x \cdot p} - 1$$

This equation represents the family of hyperbolas $q = f(p)$ for the parameters C and x.

d) formulas (42) or (50) — in order to calculate the round-trip time of outgoing, incoming and local wagons (together).

2. For this purpose, however, it is necessary to ascertain the following values:

a) at all wagon loading and unloading stations :

— the number of wagons loaded (in 24 hours) for local traffic, which will permit the calculation of U_{chk} for the entire region;

— the number of wagons loaded (in 24 hours) for outgoing traffic, which will permit the calculation of U_{che} for the entire region;

— the number of local traffic wagons unloaded in 24 hours, which will permit the calculation of U_{dk} for the entire region;

— the number of incoming wagons unloaded in 24 hours, which will permit the calculation of U_{di} for the entire region.

b) at all stations where wagons are reforwarded and received (to and from other regions) :

— the number of loaded transit wagons which have entered the region in 24 hours, which will permit the calculation of U'_{tch} for the entire region;

— the number of loaded transit wagons which have left the region in 24 hours, which will permit the calculation of U''_{tch} for the entire region;

— the number of empty transit wagons which have entered the region in 24 hours, which will permit the calculation of U'_{tv} for the entire region;

— the number of empty transit wagons which have left the region in 24 hours, which will permit the calculation of U''_{tv};

— the number of loaded incoming wagons which have entered in 24 hours, which will permit the calculation of U'_{ich} for the entire region;

— the number of empty incoming wagons which have entered in 24 hours, which will permit the calculation of U'_{iv} for the entire region.

— the number of loaded outgoing wagons which have left in 24 hours, which will permit the calculation of U''_{ech} for the entire region;

— the number of empty outgoing wagons which have left in 24 hours, which will permit the calculation of U''_{ev} for the entire region.

It goes without saying that the technical application of the method here outlined will depend on the working methods already in use with the railway administrations concerned, as well as on the technical equipment available.

[625 .2]

The transversal stability when in motion of railway vehicles on the straight.

An investigation into rocking by means of an analogue computer,

by Stig Johnsson, Västeras (Sweden).

(*Glasers Annalen*, No. 5, May 1958.)

1. Relative slip and forces between wheel and rail.

Let us suppose that a wheel of radius r and with cylindrical tread (fig. 1) rolls over a hard support (steel on steel). Let us also imagine that it supports vertically a load P_o and that the tangential force between the wheel and the rail in the direction x be X. Furthermore, let v be the speed of the centre of the wheel and $\dot{\varphi}\left(=\frac{d\varphi}{dt}\right)$ the constant angular velocity of the wheel whilst rolling.

We will then call *relative slip* (Kriechen, slip, creep, creepage) the relation :

$$\frac{\text{movement of the centre} - \text{rolling of the wheel}}{\text{rolling of the wheel}} = \varepsilon = \frac{dx - r\,d\varphi}{r\,d\varphi} = \frac{v}{r\dot{\varphi}} - 1 \qquad (1)$$

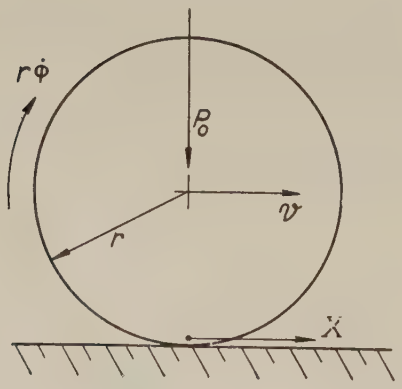


Fig. 1. — Definition of the frictional forces.

and we will endeavour to ascertain the possible relation between ε and X. So far as the author is aware, no theoretical solution of this problem has been published which would be valid for all values of ε. On the other hand, a number of experimental studies [1, 2] (1) have been carried out. The curve of figure 2 seems to provide a reasonably good approximation of the actual conditions (2). Analytically, it can be represented by approximation by the following equation :

$$\frac{X}{\mu P_o} = -\frac{\varkappa}{\mu}\varepsilon\left[1 + \left(\frac{\varkappa}{\mu}\varepsilon\right)^2\right]^{-0.5} \qquad (2)$$

in which :

P_o = pressure of the wheel;

μ = coefficient of friction fully established;

$\varkappa$ = constant.

This constant $\varkappa$ should be chosen in such a way as to permit the best adaptation to the curve (fig. 2).

For high values (positives) of ε, (2) can be written $X = -\mu P_o$, as would be

(1) The figures within brackets refer to the bibliography at the end of the article.

(2) This curve naturally is the weak point of the present theory (and of all analogous theories) and this is not only because its real character is unknown. It is most probable that it varies with the atmospheric conditions, with the roughness of the rail and wheel surfaces, etc. In practice, therefore, the curve ought in reality to be transformed into a surface, the limiting curves of which should represent the optimum possibilities.

expected. For low values of ε, or more exactly for $\frac{\varkappa\varepsilon}{\mu} \ll 1$, we get :

$$X = -\varkappa P_o \varepsilon$$

or when $F_o = \varkappa P_o$:

$$X = -F_o \varepsilon \qquad (3)$$

so that in this case, the force is a lineal function of ε. The constant of proportionality F_o (which has the dimension of a force) is then simply the initial slope of the curve (fig. 2).

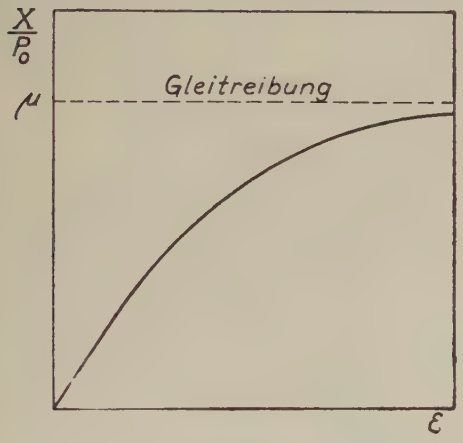


Fig. 2. — The frictional force X as a function of the relative slip ε.

N. B. — Gleitreibung = frictional slip.

If the relative slip is defined relatively to two fixed directions x and y by ε_x and ε_y, the resultant becomes :

$$\varepsilon = \left(\varepsilon_x^2 + \varepsilon_y^2 \right)^{0.5}$$

and the total frictional force as above :

$$R = -\mu P_o \frac{\varkappa\varepsilon}{\mu} \left[1 + \left(\frac{\varkappa\varepsilon}{\mu} \right)^2 \right]^{-0.5}$$

in which μ is supposed to be independent of the direction. The forces directed along the axes of the x's and the y's are then :

$$\left.\begin{aligned} X &= \frac{\varepsilon_x}{\varepsilon} R \\ Y &= \frac{\varepsilon_y}{\varepsilon} R \end{aligned}\right\} \qquad (4)$$

It can easily be shown that for large values of $\left(\frac{\varkappa\varepsilon}{\mu} \gg 1, \right)$ we get approximately :

$$X^2 + Y^2 = \mu^2 P_o^2$$

If for example ε_x is very large and negative, we find $X = \mu P_o$ and $Y = 0$. If consequently, the whole of the available friction is taken advantage of to make the wheel advance, no friction remains to cause the transverse displacement. It will be comparable, for example, with the skidding of the rear axle of an automobile when trying to start uphill on a road covered with ice.

Thanks to the great help to be got from an analogue computer, it would be readily possible to elaborate the rest of the theory starting from non-linear equations (4). But at the beginning of a study — and this theory does not go much further — it is desirable to establish the equations in the simplest possible form. Furthermore, the calculations show that for a normal play in the track and the usual speeds, the relative slip has in fact values so low that it is sufficient to take into account the first part of the curve which rises in almost a straight line (fig. 2). This it is true is only applicable in the absence of braking forces or of heavy tractive power.

Consequently, no serious error would be committed in writing equation (4) in a linear form which gives :

$$\left.\begin{aligned} X &= -F_o \varepsilon_x \\ Y &= -F_o \varepsilon_y \end{aligned}\right\} \qquad (5)$$

In this form, although with other designations, the relative slipping forces have been

considered already in numerous calculations. CARTER [3] appears to have been the first to have treated the problem of stability under a simplified form, followed subsequently by others [4, 5, 6, 7].

A good approximation for F_o [4, 6, 7] is given by :

$$F_o = 15\,000 \sqrt{P_o \cdot r} \qquad (6)$$

in which :

P_o = load on wheel in kilogrammes;

r = radius of the wheel in metres;

F_o is expressed in kilogrammes.

2. **The isolated axle.**

We will now establish the differential equations for an isolated axle. To begin with the expressions for the relative slip of the two wheels must be looked for. Figures 3*a* and 3*c* represent, in the neutral position, an axle rolling on a rail on a straight track. Let us suppose in addition that in this position, the two rolling circles have the same radius r. Let $2s$ be the distance between centres of the bearings. A fixed system of co-ordinates xyz is adopted, in conformity with figure 3. The rotation of the pair of wheels round the axis of the z's measured by the angle Θ_1 is positive in the clockwise sense. The translation of the centre of gravity is designated by y_1, it is positive towards the right (fig. 3*b*). Let φ be the angle of rolling of the axle.

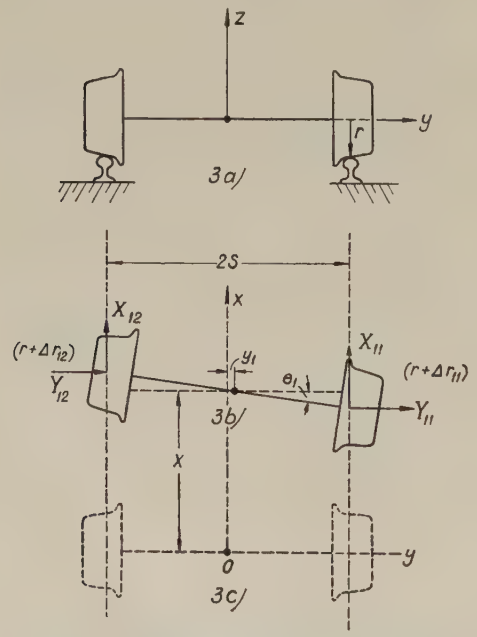


Fig. 3. — Isolated axle : co-ordinates and forces.

Figure 4 shows rather more clearly the conditions at the contact; N is the normal force whose components are P_o and $P_o \tan \delta$. The load per wheel is supposed equal for the two wheels and independent of the time. δ is the angle of contact between the wheel and the rail.

When the axle has moved by a quantity x from its initial position (fig. 3), its new position is determined by y_1, Θ_1 and φ. The rolling circles are at present for radii $(r + \Delta r_{11})$ and $(r + \Delta r_{12})$. Starting from this position, the axle travels during the time dt a distance dx. At the same time, the angles vary respectively by $d\Theta_1$ and $d\varphi$.

The centre of the right wheel moves by a quantity $(dx - s\, d\Theta_1)$ in the direction x. But in the same time it rolls by a quantity $(r + r\Delta_{11})\, d\varphi$. The relative slip will then be according to (1) :

$$\frac{dx - s\, d\Theta_1 - (r + \Delta r_{11}) \cos. \Theta_1\, d\varphi}{r\, d\varphi}$$

by making the denominator $(r + \Delta r_{11})\, d\varphi \approx r\, d\varphi$. Now cos. Θ_1, is very close to 1 and we get from (5) :

$$X_{11} = -F_0 \frac{dx - s\, d\Theta_1 - (r + \Delta r_{11})\, d\varphi}{r\, d\varphi} \qquad (7a)$$

$$X_{12} = -F_0 \frac{dx + s\, d\Theta_1 - (r + \Delta r_{12})\, d\varphi}{r\, d\varphi}$$

X_{12} is arrived at in the same manner as X_{11}.

In order to calculate the forces Y, we take cos. $\delta \approx 1$ and we neglect the small

vertical component. The right wheel moves by dy_1 in the direction of the y's and rolls at the same time by the amount $(r + \Delta r_{11})$ sin. $\Theta_1\, d\varphi$ in this direction. Making sin. $\Theta_1 \approx \Theta_1$, the relative slip then in this case becomes :

$$\frac{dy_1 - (r + \Delta r_{11})\,\Theta_1 d\varphi}{r\, d\varphi}$$

and the forces :

$$\left.\begin{aligned} Y_{11} &= -F_0 \frac{dy_1 - (r + \Delta r_{11})\,\Theta_1 d\varphi}{r\, d\varphi} \\ Y_{12} &= -F_0 \frac{dy_1 - (r + \Delta r_{12})\,\Theta_1 d\varphi}{r\, d\varphi} \end{aligned}\right\} \quad (7b)$$

Y_{12} is formed in the same manner as Y_{11}.

total frictional force in the direction of the y's becomes :

$$Y_{11} + Y_{12} = -2\,F_0 \left(\frac{dy_1}{dx} - \Theta_1 \right) \quad (9a)$$

The frictional moment becomes :

$$\begin{aligned} &(X_{12} - X_{11})\, s \\ &= -2\,F_0 s \left(\frac{s\, d\Theta_1}{dx} + \frac{\Delta r_{11} - \Delta r_{12}}{2\,r} \right) \end{aligned} \quad (9b)$$

The two components of the normal force act in the transversal direction as do the inertia forces $m\ddot{y}_1$ and $m\rho^2\ddot{\Theta}_1$ in which

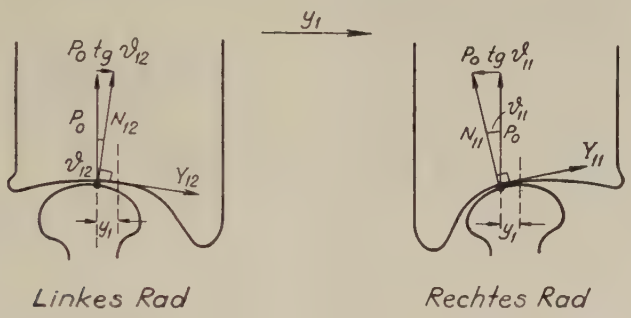


Fig. 4. — Forces applied to the flanges.
N. B. — Linkes Rad = left wheel. — Rechtes Rad = right wheel.

We suppose at present (as always) that the running speed is constant without braking or traction. We then get :

$$X_{11} + X_{12} = 0$$

and also :

$$\frac{dx}{r\, d\varphi} = 1 + \frac{\Delta r_{11} + \Delta r_{12}}{2\,r}$$

or in other words with good approximation :

$$dx = r\, d\varphi \quad (8)$$

With this equation if we again consider $\dfrac{\Delta r_{12} + \Delta r_{11}}{2\,r}$ as low relatively to 1, the

m = mass of the axle;

ρ = radius of inertia of the axle;

$$\left.\begin{aligned} \ddot{y}_1 &= \frac{d^2 y_1}{dt^2} = v^2 \frac{d^2 y_1}{dx^2} \\ \ddot{\Theta}_1 &= \frac{d^2 \Theta_1}{dt^2} = v^2 \frac{d^2 \Theta_1}{dx^2} \end{aligned}\right\} \quad \text{since } x = vt.$$

We must now take into account the force of the flange S, which is not linear. We will apply it with an elastic constant $= c_r$ (rail and wheel set in series) and a play in the track of 2σ. Instead of a straight line, a curved graph (for example progressively increasing) could be considered; for calculation with an analogue computer that in fact would not be very important.

However, this hypothesis naturally is only approximately exact even if based on a contact at two points. We should now add that we have made another simplification; we have supposed by implication that the rail does not move under the effect of the forces Y. Should we wish to take this condition into account, we ought to write everywhere where we now put y_1, $(y_1 - y_{o1})$ or $(y_1 - y_{o2})$ for the right wheel and the left wheel respectively, representing the transversal displacements of the rails.

Then, too, the force exerted by the flange sets up a frictional force $\mu_s S$ always directed forward. This force produces a moment $\mu_s S s$.

Now, we have ascertained the forces and the moments we can always establish the differential equations of the isolated axle. These are written as follows :

$$\left.\begin{aligned} mv^2 \frac{d^2 y_1}{dx^2} &= Y_{11} + Y_{12} - P_0 (tg\,\delta_{11} - tg\,\delta_{12}) - S \\ m\rho^2 v^2 \frac{d^2 \Theta_1}{dx^2} &= (X_{12} - X_{11})\, s - \mu_s S s \end{aligned}\right\} \quad (10)$$

If the profiles of the rolling surfaces are identical (even in the worn state), we can take account of the following series of odd powers of y_1 :

$$\left.\begin{aligned} 0.5\,(\Delta r_{11} - \Delta r_{12}) &= \gamma_0 y_1 + \gamma_1 y_1^3 + \ldots \\ tg\,\delta_{11} - tg\,\delta_{12} &= e_0 y_1 + e_1 y_1^3 + \ldots \end{aligned}\right\} \quad (11)$$

For conical rolling surfaces (new wheels) γ_o is equal to the conicity (for example : $1/20 = 0.05$) whilst the last expression (11) is identical with 0 because then $\delta_{11} = \delta_{12}$ for all values of y_1. In the case of worn wheels, special investigations have to be made. Figure 6 gives the result of an investigation of this kind for well worn wheels and $\sigma = 5.7$ mm. As a comparison, the values corresponding to new wheels have been indicated as well. In this case again $0.5\,(\Delta r_{11} - \Delta r_{12})$ is practically linear, the same as $(\tan \delta_{11} - \tan \delta_{12})$, and the degree of wear is characterised as a result by the two magnitudes γ_o and e_o (3).

To begin with it is useful to look for an approximative solution of (10) for new conical wheels. Neglecting the flanges and leaving aside the terms relating to the inertia, there remains simply :

$$Y_{11} + Y_{12} = 0$$
$$X_{12} - X_{11} = 0$$

and we obtain from (9) :

$$\frac{d^2 y_1}{dx^2} + \frac{\gamma_0}{rs} y_1 = 0$$

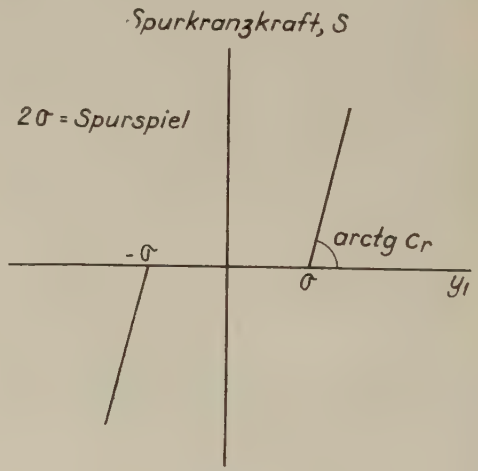


Fig. 5. — Play in the track and force applied to the flange.

N. B. — Spurspiel = play in the track. — Spurkranzkraft = force applied to the flange.

(3) In view of the small number of investigations, this is a bold conclusion. It is to be hoped that other measurements will be effected on wheels and rails at different degrees of wear. Here again, it may be remarked that mechanical calculations using non-linear expressions such as (11) above are little more complicated.

This oscillation therefore is at the boundary between stability and instability. Its length of wave is :

$$\lambda = \lambda_0 = 2\pi\sqrt{\frac{rs}{\gamma_0}}$$

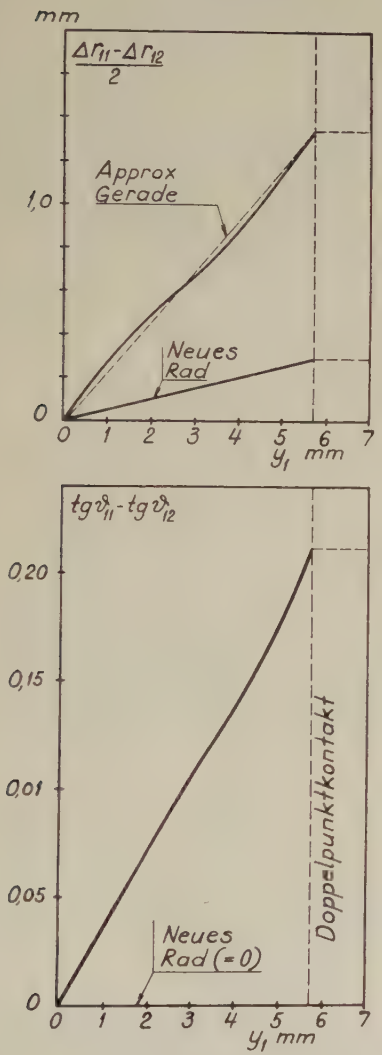


Fig. 6. — Characteristics of the tyres of a worn wheel compared with those of a new one.

N. B. — Neues Rad = new wheel. — Approx. Gerade = approximate vertical. — Doppelpunktkontakt = two point contact.

which corresponds to the value already calculated by KLINGEL. If now the inertia forces are brought into account, we get as is readily calculated a differential equation of the 4th degree. In this case the oscillation becomes unstable and the wave length increases with the speed.

If the above theories be applied to a 4-wheeled bogie with axles fixed in the frame (wheelbase $2\,a_1$), we obtain for the same approximations (no flanges, no inertia, conical wheels) the wave length :

$$\lambda = 2\pi\sqrt{\frac{rs}{\gamma_0}\left[1+\left(\frac{a_1}{s}\right)^2\right]}$$

result identical as that by ROCARD (or by CARTER).

3. **Development of the theory.**

So far, we have considered simply an isolated axle. As it constitutes a fundamental problem, we have stressed to rather a large degree the details. In the continuation of these theoretical considerations, we will not attempt a rather precise exposition because it is now a question generally speaking of known forms of the technique of oscillations.

It now becomes necessary to take into account not only the forces acting between the wheel and the rail, but also of those which enter into play between the axle and the bogie frame (or the vehicle body). For this effect, several cases ought to be considered : we will now examine two of them :

(*a*) two axle locomotive bogie with the axles having transversal play;

(*b*) ordinary bogie vehicle with sliding surfaces between the body and the bogies.

3.1. **Bogie of a Bo-Bo locomotive.**

Figure 7*a* shows the principle of such a bogie. It can therefore be represented by four co-ordinates; y_1 and y_2 for the axles and y_b and Θ_b for the frame. For greater clarity, we have ignored the springing

between the axles and the frame, in which the forces P_{a1} and P_{a2} act. These forces are a function of the co-ordinates in the following manner :

$$P_{a1} = P_{a1} (y_1 - y_b - a_1 \Theta_b)$$
$$P_{a2} = P_{a2} (y_2 - y_b + a_1 \Theta_b)$$

The forces applied to the flange can be designated as follows (see fig. 5) :

$$S_1 = S (y_1)$$
$$S_2 = S (y_2)$$

The eight frictional forces (X_{11}, X_{12}, X_{21}, X_{22}, Y_{11}, Y_{12}, Y_{21}, Y_{22}) as above are functions of the co-ordinates and their derivates. They no longer quite coincide in the present case with (7) but they can be formed here exactly in the same manner.

Let us suppose moreover :

m_1 = mass of each axle;

m_b = mass of bogie frame;

I_b = moment of inertia of the masses reduced relatively to a vertical axis passing through the centre of gravity (centre) of the frame.

We can then establish the following differential equations :

$$\left.\begin{aligned} m_1 \ddot{y}_1 &= Y_{11} + Y_{12} - P_0 (tg\ \delta_{11} - tg\ \delta_{12}) - P_{a1} - S_1 \\ m_1 \ddot{y}_2 &= Y_{21} + Y_{22} - P_0 (tg\ \delta_{21} - tg\ \delta_{22}) - P_{a2} - S_2 \\ m_b \ddot{y}_b &= P_{a1} + P_{a2} \\ I_b \ddot{\Theta}_b &= (X_{12} + X_{22} - X_{11} - X_{21})\ s + (P_{a1} - P_{a2})\ a_1 \end{aligned}\right\} \quad (12)$$

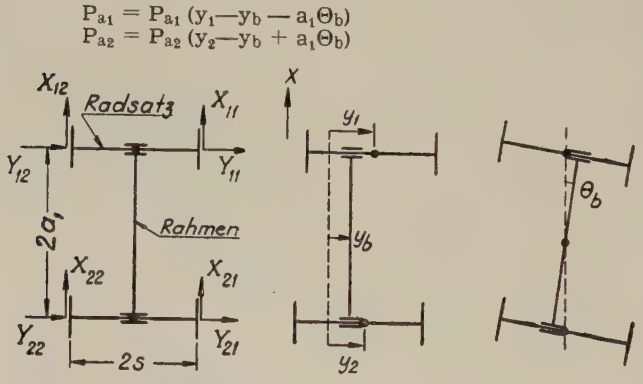


Fig. 7*a*. — Frictional forces and displacements of a bogie with two axles with lateral play.

N. B. — Radsatz = wheels and axle. — Rahmen = frame.

We have neglected herein the friction of the flange. This system is of the 8th degree with four non-linearities [if the following linear hypotheses are adopted (11)]. In order to obtain now a system applicable to the locomotive as a whole, four corresponding equations must be established for the rear bogie, plus at least three for the body. In this way, we should obtain a system of the 22nd order with (at least) eight non-linearities. These are some degrees of liberty too many for our analogue calculator in its present form. This is why we are satisfied with system (12) even

from which many interesting results can be obtained.

The wave length can be determined by a first approximation even without the assistance of a calculating machine. We will suppose the forces P_a to be linear with

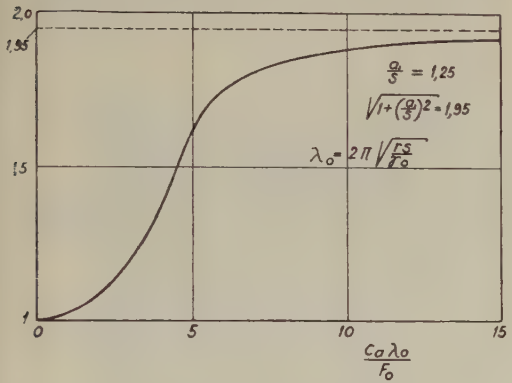


Fig. 7*b*. — Wave length of a bogie according to the simplified calculation.

a elastic steepness c_a or in other words :

$$P_{a1} = c_a (y_1 - y_b - a_1 \Theta_b)$$
$$P_{a2} = c_a (y_2 - y_b + a_1 \Theta_b)$$

We then make $S_1 = S_2 = 0$, $e_o = 0$, and the same for all inertia forces.

In this simple case, the solution is given by an equation of the third degree by which the length of the wave can be calculated. Figure 7*b* gives the wave length (based on that of KLINGEL) as a function of $\frac{c_a \lambda_o}{F_o}$ for $\frac{a_1}{s} = 1.25$ (which is not precisely a locomotive bogie). This last expression and in particular c_a has therefore a great influence. For $c_a \to \infty$ we have $\frac{\lambda}{\lambda_o} = \sqrt{1 + \left(\frac{a}{s}\right)^2}$ and we see that for $c_a \to 0$, we get $\lambda = \lambda_o$. These are the two extreme limits. Between these, $\frac{\lambda}{\lambda_o}$ follows a curve the slope of which is very steep.

— With this approximation, the hunting motion is always damped out.

If the axles have any possible movement, not only transversal, but also longitudinally (against a certain restoring force), we are almost in the case of the wagon with two orientable axles (goods wagon). Naturally, the dry friction in the joints must be taken into account.

The equations (12) naturally are applicable to *all* systems corresponding to figure 7*a*. The sole reason why in this chapter we speak of a *locomotive bogie* is that the numerical calculations have been made for such a bogie.

The same remark applies to the equations (13) below and to figure 8.

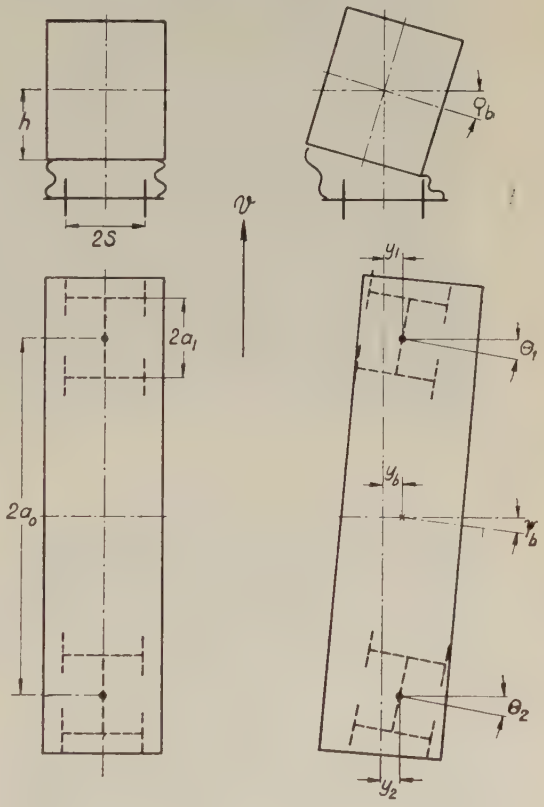


Fig. 8. — Co-ordinates of a bogie wagon.

3.2. **Bogie wagon.**

To end, we will establish the differential equations for a bogie wagon (fig. 8), whilst supposing that the axles have no side nor longitudinal play in the frame.

The leading bogie has for ordinates y_1 and Θ_1, the rear bogie y_2 and Θ_2. For the body, we take into account three forms of oscillations :

Transversal oscillations . . . . . y_b
Rolling . . . . . φ_b
Pivoting . . . . . ψ_b

The applied transversal forces between the bogies and the body are then :

$$P_1 = c_y [y_1 - (y_b + a_o\psi_b - h\varphi_b)] = c_y\delta_1$$
$$P_2 = c_y [y_2 - (y_b - a_o\psi_b - h\varphi_b)] = c_y\delta_2$$

and are supposed to be linear.

In these formulae :

$2\,a_o$ = distance between bogie pivots;

h = height of body centre of gravity above the springs;

c_y = transversal stiffness of the springs between the body and bogie.

The moments related to the vertical axes between the body and the bogie can be written :

$$M_1 = M_0\, sgn\,(\dot{\Theta}_1 - \dot{\psi}_b)$$
$$M_2 = M_0\, sgn\,(\dot{\Theta}_2 - \dot{\psi}_b)$$

M_o is the moment of friction due to the sliding surfaces. In the present study, it is supposed to be constant. The rolling of the body on the springs is opposed by a restoring movement :

$$-(c_y h\,\delta_1 + c_y h\,\delta_2 + 2\,c\varphi\,\varphi_b)$$

$c\varphi$ being the common moment of the vertical suspension of the bolster and of the axles of each bogie.

The forces applied at the flange S_1, S_2, S_3, S_4, should be developed according to figure 5. But instead of y_1, this time $(y_1 + a_1\,\Theta_1)$ must be written for S_1, $(y_1 - a_1\,\Theta_1)$ for S_2, etc. Naturally these forces also give rise to moments.

If Y_1, Y_2 be the transversal frictional forces of the two bogies and $M\theta_1$ and $M\theta_2$ the corresponding moments, their magnitudes can be determined by the method given above.

Finally, the following designations are introduced :

m_1 = mass of each bogie;
I_1 = moment of inertia of each bogie relatively to a vertical axis passing through the centre of gravity;
m = mass of the body;
I_{xy} = moment of inertia of the body relatively to a vertical axis through the centre of gravity;
I_{yz} = moment of inertia of the body through a longitudinal axis through the centre of gravity.

The differential equations now can be written as follows :

$$\left.\begin{aligned}
m_1\ddot{y}_1 &= Y_1 - c_y\delta_1 - S_1 - S_2\\
I_1\ddot{\Theta}_1 &= M_{\theta\,1} - M_1 - S_1a_1 + S_2a_1\\
m_1\ddot{y}_2 &= Y_2 - c_y\delta_2 - S_3 - S_4\\
I_1\ddot{\Theta}_2 &= M_{\theta\,2} - M_2 - S_3a_1 + S_4a_1\\
m_b\ddot{y}_b &= c_y\delta_1 + c_y\delta_2\\
I_{xy}\ddot{\psi}_b &= c_ya_0\delta_1 - c_ya_0\delta_2 + M_1 + M_2\\
I_{yz}\ddot{\varphi}_b &= -c_yh\delta_1 - c_yh\delta_2 - 2c_\varphi\,\varphi_b
\end{aligned}\right\} \quad (13)$$

For simplification, the transversal components of the normal forces between the wheel and rail (for example : $P_o\ [\tan\delta_{11} - \tan\delta_{12}]$) and the friction of the flange have been ignored here.

If we should now wish to introduce a damping of the speed fitted in parallel with the springing, $c_y\delta$ must be replaced everywhere by $\left(c_y\delta + k_y\frac{d\delta}{dt}\right)$ and $c_\varphi\varphi_b$ by $\left(c_\varphi\varphi_b + k_\varphi\frac{d\varphi_b}{dt}\right)$. k is then a constant

of damping. The term $k\bar{\varphi}$ includes the vertical damping of the bolster as well as that of the springing of the axle. All the values of c and k are calculated *per bogie*.

The system of equations (13) is of the 14th degree. All the forces S, as also M_1 and M_2 are non-linear.

composed of concentrated masses and of springs. This leads to differential equations (linear or not) with a *single variable* (time) which constitutes as it were the ideal language for an analogue calculator. In this calculation, we can then start directly from systems of equations such as (12)

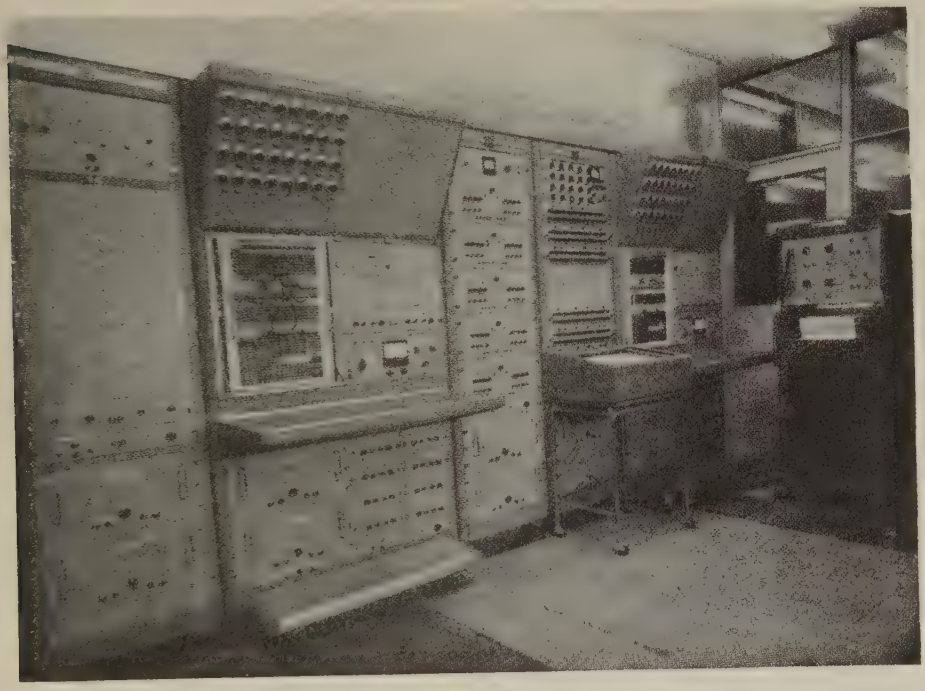


Fig. 9. — Analogue computer.

4. **The analogue calculator.**

The functioning of an analogue calculator, as is known, is characterised by the fact an *analogy* (or a model) is got out for the physical system to be studied. We will not give a detailed description of it here because the publications dealing with it are already very numerous [8].

In our case, there is no doubt that an analogue calculator is to be preferred to a numerical calculator and in particular because the physical oscillating system is

or (13). All that is necessary is to take care to select the suitable scale.

Our machine (fig. 9) contains forty amplifiers, sixteen of which can be used as integrators (which makes it possible to study equations up to the 16th order). For the make up of non-linearities, six generators of functions are available as well as five multipliers. The different oscillations can be recorded by means of a 4-channel recorder and a recorder of co-ordinates. The builder was Electronic Associates Inc.

5. Numerical calculation. Selected results.

The systems (12) and (13) have a large number of parameters. The order of magnitude is 10 to 20. Even though some of them are already given by the construction (for example the masses, certain lengths), there remain many which it is necessary to vary. One of the greatest difficulties of the calculation is precisely a clear vision with such a quantity of constants. The general solution consequently is enlarged.

For this reason, it is obviously impossible in this article to give a systematic exposition of the results. We have to be satisfied to study the influence of some parameters whilst leaving the others invariable.

Furthermore, we have to take into account that no outside force or other perturbation is contained in the equations (12) and (13). The vehicle (bogie) and the track constitute a closed system in itself which — as we shall see shortly — can be either stable or unstable. By stability, we understand here that the oscillations damp themselves out little by little after an isolated perturbation (for example slight transversal displacement of a bogie, co-ordinate y_1).

We call a system unstable when subsequent to a perturbation, the amplitudes continue to increase to a certain magnitude at which they stabilise (stationary oscillation). This last case signifies in general (but not always) that the flanges constantly come into contact with the rails on the two sides.

In order to take into account irregularities (transversal or vertical) of the layout of the permanent way, corresponding magnitudes ought to be introduced into the equations. This operation in itself does not present any difficulty; the difficulty is to measure exactly these irregularities on an actual track over long distances. As the start of a study of this kind, we have investigated to a slight extent the transversal variations in the layout of the track under the form of sinusoidal waves.

We treat separately hereafter the resolution of the systems of equations (12) and (13).

5.1. Bo-Bo bogie.

In the calculation, we admit the bogie has the normal load even though there is no body.

The following values have been used :

Load per axle	P_o	= 10.5 t
Mass of the axle	m_1	= 225 kgs^{2}m^{-1}
Mass of the bogie minus the axles	m_b	= 1 700 kgs^{2}m^{-1}
Moment of inertia	I_b	= 3 900 kgs^{2}m
Distance between centres of bearings	$2s$	= 1.5 m
Circumferential radius	r	= 0.65 m
Wheelbase	$2a_1$	= 3.20 m
Total play in the track	2σ	= 0 – 20 mm
Transversal stiffness (rail and wheel in series)		= $0.7 \cdot 10^6$ kg+m^{-1}
Tyres constants	γ_o	= 0.05 – 0.15
	e_o	= 0 – 11 m^{-1}
Speed	v	= 36 – 150 km/h.

With these data, formula (6) gives : $F_o = 1.2 \cdot 10^6$ kg. We have however used a value 40 % higher (4).

The transversal springing between the axles and the frame has a particular interest. Three cases have been studied in detail :

1) with preliminary tension;
2) with play;
3) with a recoil force increasing linearly over a range of 5 mm with a stiffness of c_{a1} then one of $c_{a2} = 20 \cdot 10^6$ kg/m (the whole per axle). See figure 10*a*.

Figures 10*c* and 10*d* represent for new and worn wheels the areas of stability and instability in the case of this last realisation [full line curve (5)]. This limit to which in consequence $q_1/q_0 = 1$ (fig. 10*b*) obviously presents a mathematical interest, but in practice it is of little importance. For this reason, we have also calculated the

(4) At the period these calculations were made, we in fact used another relation than (6). According, however, to previous works subsequently coming to the author's notice (6) corresponds more closely to reality. This remark is also applicable to the bogie wagon.

limits for $q_1/q_0 = 0.50$ and 0.30. There are therefore very marked maximum values which are slightly smaller for worn tyres. Moreover, for new wheels the areas bounded by the broken line curve are appreciably more restricted. In the present case, there is therefore only deterioration through wear for the small values of c_{a1}. As can be seen

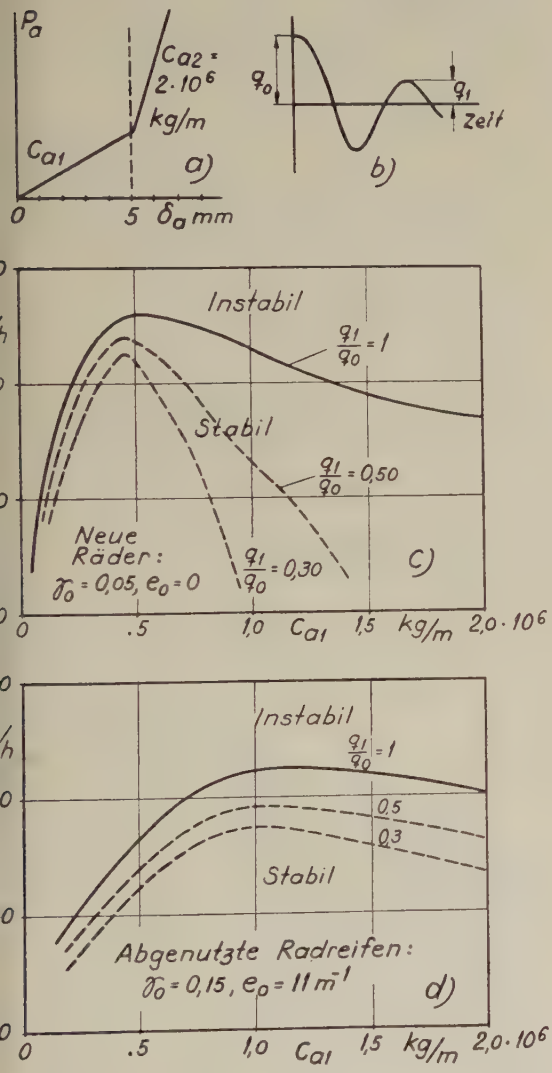


Fig. 10. — Fields of stability of a two axle bogie. Total play in the track $2\sigma = 20$ mm.

c_{a1} = approximately $0.7 \cdot 10^6$ kg/m is a value which ensures good stability over the whole period of wear.

Figure 11 gives the wave length (measured on y_b) for three speeds as functions of c_{a1}. The dotted parts indicate that in this region the values are uncertain (as a result of heavy damping of the oscillations, it is in fact difficult to measure with exactitude the wave lengths on the diagrams). The general pattern of these curves agrees reasonably well with that of figure 7*b*.

An investigation was also made into the influence of a periodical transversal perturbation in the track (sinusoidal of 20 m wave length and of amplitude y_o with concordance of phase in the two rails). Figure 12 gives the total force applied to the rail (and not simply the force applied by the flange) as a function of y_o for $v = 60$ and 120 km/h and for two different designs of the transversal springing of the axle.

To end this part, it is again well to point out that the calculations and the results relate to an isolated bogie. This does not mean that any particular conclusion can be come to as a result for a complete locomotive.

5.2. **Bogie wagon.**

In the case of the bogie wagon (fig. 8) the following magnitudes have been adopted as data :

Load per wheel .	P_o =	5.5 t
Mass of one bogie	m_1 =	612 kgs²m⁻¹
Moment of inertia of the bogie . . .	I_1 =	1 000 kgs²m⁻¹
Mass of the body .	m_b =	3 060 kgs²m⁻¹
Moment of inertia of the body . . .	I_{xy} =	140 000 kgs m²
	I_{yz} =	4 950 kgs m²
Distance between centres of the bearers	$2s$ =	1.5 m
Distance between pivots	$2a_o$ =	18 m

(5) All the curves refer to the ordinate yb or in other words to the transversal displacement of the bogie frame.

Distance between wheel centres	$2a_1 =$	2.6 m
Height of centre of gravity	$h =$	1.25 m
Radius of the wheel	$r =$	0.483 m
Total play in the track	$2\sigma =$	20 mm
Transversal stiffness of the wheel and of the rail	$c_r =$	$1.5 \cdot 10^6$ kg m^{-1}

In the calculations the following magnitudes were varied :

- Coefficient of friction between the sliding surfaces . . . . . μ
- Transversal stiffness of the springing of the bolster . . . . . c_y
- Vertical stiffness of the bolster and axle suspension . . . . . c_z
- Transversal damping constant of the bolster suspension . . . . . k_y
- Damping constant of the vertical springing . . . . . k_z (6)
- Speed v
- Conicity of the tyre . . . . . γ_0 (7)

In the present case, it appeared useful to bring out into the clear as a start the conditions of stability.

These are now *conditioned* by the fact that they depend upon the initial state (a well known consequence of the fact that the equations are not linear). The leading bogie is given an initial value y_{1s} [that is a transversal displacement (8)] and the properties of the resulting oscillation are studied as a function of the speed. Figure 13*a* shows what occurs with new tyres ($\gamma_0 = 0.05$). When $v < 165$ km/h, and for small perturbations (for example : $y_{1s} = 3$ mm), the nosing damps out. When $v = 100$ km/h and $y_{1s} = 8$ mm, for example, the amplitude increases and the flanges end

(6) c is given (even in the text of the figures) in kg m^{-1}, k in kg m^{-1}s.

(7) In this example, $e_0 = 0$.

(8) It would be more accurate were we to speak of an equivalent transversal displacement because in practice a perturbation arising from the track affects two ordinates (to wit : y_1 and Θ_1).

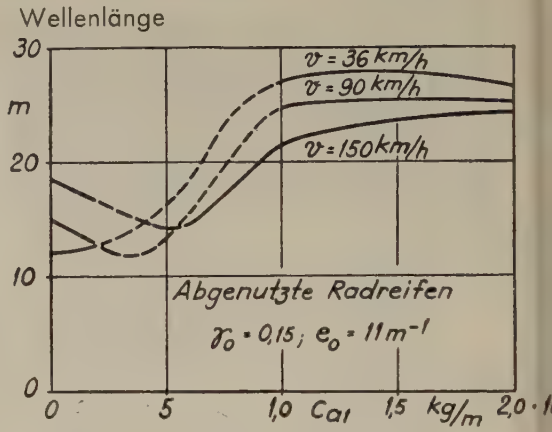


Fig. 11. — Wave length of the bogie — $2\sigma = 20$ mm.

N. B. — Wellenlänge = wave length. — Abgenutzte Radreifen = worn tyres.

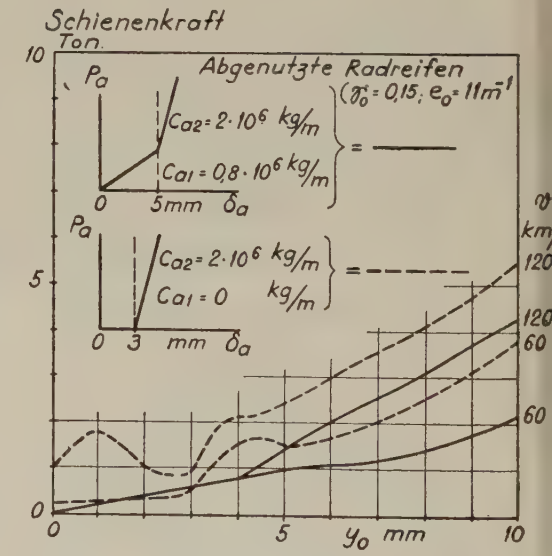


Fig. 12. — Total force applied to the leading wheel of the two axle bogie for two different types of transversal suspension of the axle, for a transversal perturbation in the track of 20 m wave length and amplitude of $xy_0 \cdot 2\sigma = 20$ mm.

N. B. — Schienenkraft = force applied to the wheel. — Abgenutzte Radreifen = worn tyres.

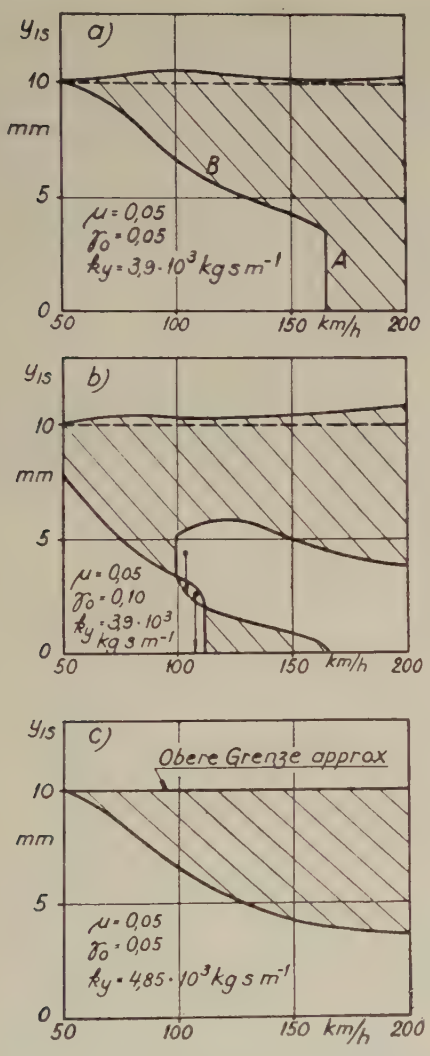


Fig. 13. — Fields of stability of the bogie wagons. The hatched surfaces are the fields of increasing amplitudes. The non-hatched surfaces are the fields of decreasing amplitudes :

$$c_y = 2 \cdot 10^4 \text{ kg m}^{-1};$$
$$c_z = 1 \cdot 10^5 \text{ kg m}^{-1};$$
$$k_z = 1 \cdot 10^4 \text{ kg sm}^{-1}.$$

N. B. — Obere Grenze approx. = upper limit approximately.

by striking the rail (when $y_{1s} = 10$ mm) and spreading the rails slightly inwards. We also see that on the range $165 < v < 200$, the oscillation is always unstable.

When $\gamma_0 = 0.10$ (worn tyres), the conditions of stability modify themselves appreciably (fig. 13*b*) and for other combinations of various magnitudes, the situation becomes so complicated to the point that it can only be mastered with the greatest difficulty. For example, this is why the position of the vertical branch of curve A in figure 13*a* depends, amongst other things, on γ_0, c_y, c_z, k_y, k_z. An increase of k_y for example displaces it to the right and its range of stability becomes wider (fig. 13*c*). Contrarily, the B branch of the curve only varies with μ with which it is almost proportional. We might be tempted to believe that the best way to improve the stability would be to increase markedly the friction between the rolling surfaces. Unfortunately, it appears not to be quite so simple. A higher value of μ means amongst other things more considerable forces in the initial curves and at the places where there are discontinuities. Figure 14 indicates the first (and greatest) amplitude of the force exerted by the flange in the case of a start at angle with $\Theta = 0.003$ rad. It must not be forgotten, furthermore, that a railway never conforms with the ideal conditions herein supposed, and that the role played by the friction between the sliding surfaces in the case of a bad track layout has still to be investigated.

It is not, however, absolutely necessary to endeavour to obtain stability. Figure 15 shows the variation of $a_0\ddot{\psi}b$ [relatively to the terrestial acceleration (9)], i.e. the transversal acceleration of the body above the middle of the bogies owing to the pivoting, for four different combinations of c_y and k_y. In all cases, the running of the wagon is unstable in the meaning of the word used herein. As can be seen, the body accelerations nevertheless can be much

(9) In the case of the wagon with which we are dealing, this co-ordinate has the greatest amplitudes. Those of $\dot{y}b$ and $h\ddot{\psi}b$ are definitely less.

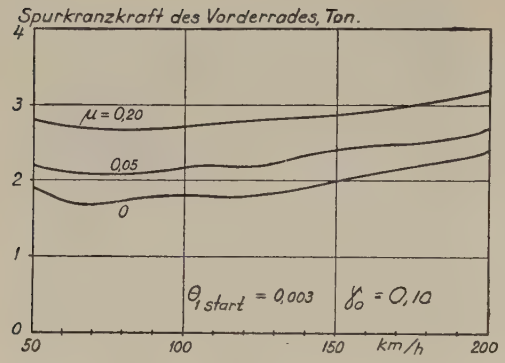


Fig. 14. — Force applied to the leading wheel flange of the bogie wagon in the case of « starting at an angle » with $\Theta_1 = 0.003$ rad. as a function of the speed and of the coefficient of friction μ of the sliding surfaces.

N. B. — Spurkranzkraft des Vorderrades, Ton = force applied to the flange of the leading wheel, tons.

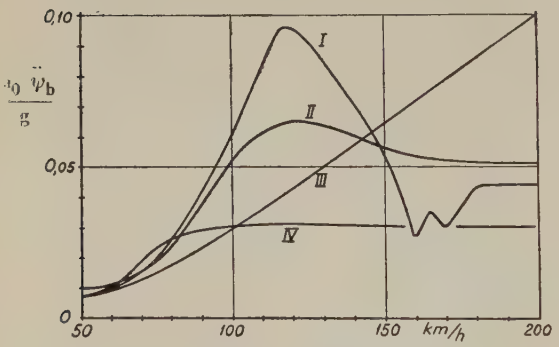


Fig. 15. — Transversal acceleration $a_o\ddot{\psi}b$ (relatively to the terrestial acceleration g) of the body under the pivoting effect measured above the centre of the bogie :

$c_z = 7 \cdot 10^4$ kg m–1, $k_z = 1 \cdot 10^3$ kg sm–1,
$\gamma_o = 0.05$, $\mu = 0.05$.

In addition :

	c_y kg m–1	k_y kg s m–1
Curve I	$4 \cdot 10^4$	$2.7 \cdot 10^3$
Curve II	$4 \cdot 10^4$	$3.75 \cdot 10^3$
Curve III	$4 \cdot 10^4$	$1.0 \cdot 10^4$
Curve IV	$2 \cdot 10^4$	$3.75 \cdot 10^3$

reduced by suitable constructional methods. Actually many wagons are unstable in running in this kind of way.

Figure 15 also shows that phenomena *analogous* to resonance can be produced because no force or other exterior periodic perturbations exist.

Another important question is that of the bogies being out of phase (y_1 and y_2). Figure 16 gives two examples of the variation of this angle with the running speed.

6. **Conclusion.**

The question of the nosing motion is frequently dealt with theoretically in the following manner : the frictional conditions between the wheel and the rail are left on

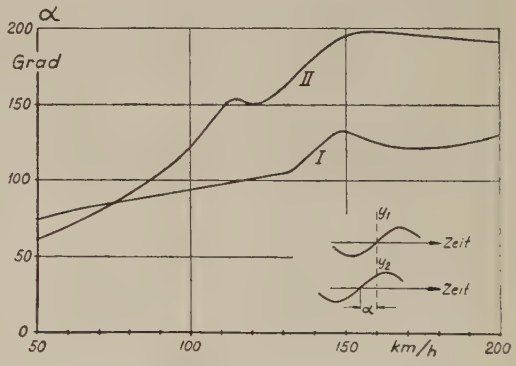


Fig. 16. — Angle of out of phase of the bogies as a function of the running speed :
$c_y = 4 \cdot 10^4$ kg m–1, $\gamma_o = 0.10$, $\mu = 0.05$.

	c_z kg m–1	k_y kg s m–1	k_z kg s m–1
Curve I	$1.34 \cdot 10^5$	$1 \cdot 10^4$	$5 \cdot 10^3$
Curve II	$7 \cdot 10^4$	$3.75 \cdot 10^3$	$1 \cdot 10^3$

one side. In return, we admit that the bogie (or the axles) displace themselves by following a sinusoidal path of amplitude equal to half the play in the track. The length of the wave is calculated by KLINGEL's method (ROCARD) independently of the running speed and the springing conditions. The phase angle between the bogies remains undetermined like the force applied at the flanges and at the rails.

In a more general way, the oscillations of the bogies are considered as absolutely independent of those of the body. They play therefore the role of causes of exterior perturbations and the problem of the hunting movement is simplified to that of ordinary resonance.

In the theory we have established herein, on the contrary, the vehicle and the track constitute a coherent system which can be either stable or unstable. On an ideally straight line, there are no exterior perturbations. *Each* co-ordinate (including therein the forces) is entirely determined in amplitude and in phase.

In order to be able to take advantage of this theory, it is absolutely essential to have the use of a calculator and the author considers preference should be given to an analogue computer for problems of this or a similar nature. Amongst others, this machine has two great advantages :

(1) It enables problems insoluble without a machine to be resolved without difficulty;

(2) The resolution is quick, and extremely numerous combinations of different parameters can be studied. With practical tests « test runs — modification of a spring — test run », it is necessary to count on several days. The analogue computer supplies the result in one minute.

The cardinal question which now poses itself is however : What relation exists between this theory and reality ! ... « as too often reality takes upon itself to reverse the most beautiful theoretical reasonings and the hopes raised by these » [9].

The author has had few chances of replying to this question. What we can say is that based on our previous tests, nothing acts to *contradict* this theory. Obviously, it is necessary to prove the validity thereof on an actual track with actual vehicles. In their present form, the theoretical considerations are limited because (apart for a few exceptions), they are only applicable to a perfectly straight line and the first difficulty will be to find one for the experimental verification to come. If the results from this are positive, it would be necessary to develop progressively these considerations so that in the end they would be applied equally well to lines straight in practice or to curves (and to the degrees of freedom still wanting on the vehicles). This appears particularly necessary if we consider to what high degree we find the kind of track reflected in the displacements of the vehicle.

The present article has to be considered as a trial and a beginning. It is also intended to draw attention to the extraordinary possibilities modern automatic computers offer in the field considered.

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[656 .25]

The probability of delays caused by conflicting movements,

by J. L. Verbeek, Engineer.

(*Spoor- en Tramwegen*, No. 21, October 9, 1958.)

If the route of a train partly coincides with that of another train, these trains may hinder each other if they follow each other too closely.

One of the objectives in compiling the timetables is to work out a plan where the influence of such clashes, which may be unilateral or bi-lateral, is kept below an economically justified level. Moreover, it is necessary to take the effect of late-running into account.

The timetables may be upset by many causes : atmospheric conditions (such as wind and snow), and imperfections in train driving where the human factor plays a part.

In the following, the attempt is made to determine a value W, representing the probability of trains delaying or blocking each other, which will enable us to study the problem of delays more closely. We shall confine our considerations to that part of a line where the influence of delays is most marked and where the length of jointly used route is negligible, i.e. at the *crossing of two routes on the level.*

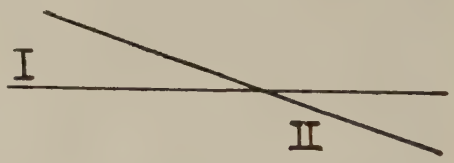
This part of a railway layout creates certain problems in organising the running of the trains, such as :

1. What is the probability of a train being delayed at such crossings, and what is the duration of the delay, expressed in units of time? From a timetable technical point of view, it is desirable to know the probability of such a delay in the case of a given interval between trains.

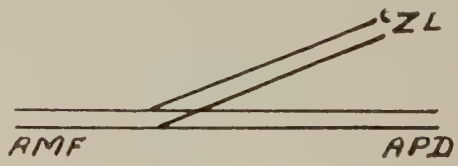
2. What is the probability of delay on a section with several crossings?

3. How great must the headway be between two trains using conflicting routes, if W shall not exceed a given value?

4. How must the timing of a train on route II be arranged between two trains on a conflicting route I, if the probabilities of clashing are to be in a given relation to each other? It is assumed that the



trains on route I do not hinder each other. Imagine the situation illustrated here where headways between trains over conflicting routes are deliberately kept short in order to reduce the interchange times at interchange stations.



5. How many trains per hour, running at given intervals, can pass over two conflicting routes if the probability of clashing is to remain within acceptable limits from an operating point of view?

This problem is very interesting as it governs the decision whether or not the train frequency can be increased, and whether or not it is necessary to build

costly engineering structures such as flyovers.

If the trains work strictly in accordance with the timetable, and if the condition $W = 0$ is to be laid down, the solution of problem (3) is found by determining the total time required for the block occupation which comprises the time during which the crossing is actually occupied, the time required for the operation of the block, and a certain time margin, e.g. for the reaction time of the operating staff. The moment at which a train can follow the preceding train over the crossing is determined by adding this (minimum) headway to the time at which the first train passed over the crossings (1).

In practice, however, the actual time shows a unilateral scatter above the earliest movement at which the occupation of the crossing can begin (2).

The causes for such delays may be ascertained from the reports of train staff, platform staff and footplate staff. They may depend on the promptness with which the train is despatched, on the driver's performance in getting the train away, and on the prompt operation of the signals.

The following calculations (3), which deal with normal operating conditions (to the exclusion of exceptionally severe weather conditions and other abnormal causes of disorganisation), are therefore based on the assumption of an asymmetrical function $p(t)$ representing the (generally variable) elementary probability of a train arriving at a given point of the track and, more particularly, at the crossing point of two routes. If the ordinates represent relative values (frequency ratios), this function must satisfy the basic condition that the area limited by the time axis, the two extreme ordinates and the function itself must be equal to 1.

Hence :

$$\int_0^T p\,(t)\,dt = 1$$

i.e. it being certain that a train arrives in the time interval between $0 \rightarrow T$.

If all the possibilities of arrival occur in the time interval between $0 \rightarrow \infty$, the relation becomes :

$$\int_0^\infty p\,(t)\,dt = 1\,.$$

The numerical examples concern either constant functions which have the same (maximum) value over the whole range, or uniformly decreasing functions which have their maximum at the origin.

A steep incline of the function is an indication of a favourable time scatter.

Consider two trains which have their earliest arrival times at 0 and a and assume

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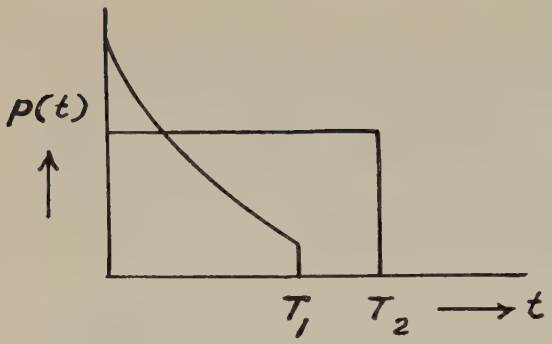
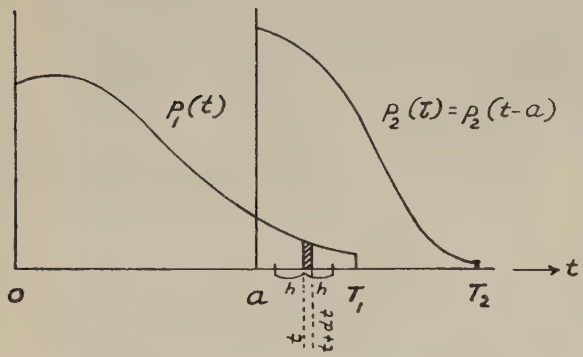
(1) This implies that the total occupation time is governed not only by the actual occupation time t (which can be calculated as $t = \frac{L}{V}$ from the two, generally not constant, values L = train length and V = train speed) but also on the signalling system; with modern safety installations, where the block operating times are shorter, the probabilities of clashing can, for the same timetable, be expected to be reduced so that it becomes easier to increase the train frequency (cf. problem 5).

(2) In view of the condition that the train may not depart before the prescribed time, the moment at which the occupation of the crossing begins is governed by the period of time required to cover the distance concerned. With the aid of formulas based on the theory of motion, these periods of time can be calculated from the distance between departure point and crossing, from the speed authorized on the rail section concerned, and from the train characteristics such as weight, starting power and brake power. Practice will show whether there is a value to be preferred for this period of time.

(3) Regarding the method, cf. the article : « Wachttijdproblemen bij treinverkeer » (Waiting time problems with train operation), by Professor W.Th. Bähler and Engineer J.L. Verbeek in *Electrotechniek* of 14th November, 1957.





that both require the same time h for the occupation of the crossing.

To train 1 applies the function $p_1(t)$, defined in the interval $0 \leq t \leq T_1$ and to train 2 the function $p_2(\tau) = p_2(t - a)$, defined in the zone $a \leq t \leq T_2 \equiv 0 \leq \tau \leq T_2 - a$; where a is the pre-determined interval between trains.

The probability that train 1 arrives at the moment t is $p_1(t)\,dt$. The probability that the second train arrives between the times $t - h$ and $t + h$ is :

$$\int_{\tau=t-a-h}^{t-a+h} p_2(\tau)\,d\tau$$

The possibility of one of the trains clashing with the other, if the first train arrives at the moment t, is :

$$p_1(t)\,dt \int_{\tau=t-a-h}^{t-a+h} p_2(\tau)\,d\tau$$

The possibility of the trains clashing between the moments $t = a + h$ and $t = T_1$ is :

$$\int_{t=a+h}^{T_1} p_1(t)\,dt \qquad \int_{\tau=t-a-h}^{t-a+h} p_2(\tau)\,d\tau$$

Between the moments $t = a - h$ and $t = a + h$, a change of limits takes place. This period yields the following possibility :

$$\int_{t=a-h}^{a+h} p_1(t)\,dt \qquad \int_{\tau=0}^{t-a+h} p_2(\tau)\,d\tau$$

The « probability of clashing based on the complete determination of the time at conflicting movements [4] » is determined from the formula :

$$W = \int_{t=a+h}^{T_1} p_1(t)\,dt \int_{\tau=t-a-h}^{t-a+h} p_2(\tau)\,d\tau + \int_{t=a-h}^{a+h} p_1(t)\,dt \int_{\tau=0}^{t-a+h} p_2(\tau)\,d\tau$$

This equation is only valid for :

$$T_1 - a \geq 2h$$
$$a \geq h$$
$$T_2 - T_1 \geq h$$

Numerical examples.

1. *Constant elementary probabilities :*

$$p_1(t) = \frac{1}{T_1}$$

in the interval $0 \leq t \leq T_1$;

$$p_2(\tau) = \frac{1}{T_2 - a}$$

in the interval :

$$0 \leq \tau \leq T_2 - a \equiv a \leq t \leq T_2 ;$$

(4) Cf. the corresponding article by M. H.P.D. van Wijk, Hon. Chief Inspector, Netherlands Railways, in *Spoor- en Tramwegen* of 16th February, 1956.

$$W = \frac{2h}{T_1} \cdot \frac{T_1 - a}{T_2 - a}$$

2. *Simple* ε *functions :*

$$p_1(t) = \frac{1}{1 - \varepsilon^{-T_1}} \cdot \varepsilon^{-t}$$

in the interval : $0 \leq t \leq T_1$;

$$p_2(\tau) = \frac{1}{1 - \varepsilon^{-(T_2 - a)}} \cdot \varepsilon^{-\tau}$$

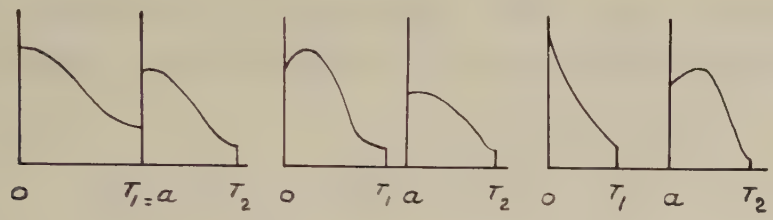
in the interval :

$$0 \leq \tau \leq T_2 - a \equiv a \leq t \leq T_2 ;$$

$$W = \frac{1}{2\,(1 - \varepsilon^{-T_1})\,(1 - \varepsilon^{-(T_2 - a)})} \cdot$$

$$\cdot \left\{ \varepsilon^{-(2T_1 + h - a)} - \varepsilon^{-(2T_1 - h - a)} - \varepsilon^{-(a + h)} + \varepsilon^{-(a - h)} \right\}$$

Special cases.



1) $a = T_1 \rightarrow W =$

$$\int_{T_1 - h}^{T_1} p_1(t)\,dt \qquad \int_{0}^{t - T_1 + h} p_2(\tau)\,d\tau ,$$

where $h \leq T_1$ and $h \leq T_2 - T_1$

2) $a - T_1 < h \rightarrow W =$

$$\int_{a - h}^{T_1} p_1(t)\,dt \qquad \int_{0}^{t - a + h} p_2(\tau)\,d\tau ,$$

where $h \leq a$ and $h \leq T_2 - T_1$

3) $a - T_1 \geq h \rightarrow W = 0$;

most favourable case, but with low frequency.

Numerical examples for case 2.

a) *Uniform elementary probabilities :*

$$p_1(t) = \frac{1}{T_1} \text{ and } p_2(\tau) = \frac{1}{T_2 - a},$$

both defined within the limits indicated above.

$$W = \frac{(T_1 + h - a)^2}{2\,T_1\,(T_2 - a)}$$

Limit case :

$$a - T_1 = h \rightarrow W = 0 .$$

b) *Simple* ε *functions :*

$$p_1(t) = \frac{1}{1 - \varepsilon^{-T_1}} \cdot \varepsilon^{-t}$$

and :

$$p_2(\tau) = \frac{1}{1 - \varepsilon^{-(T_2 - a)}} \cdot \varepsilon^{-\tau}$$

$$W = \frac{1}{(1 - \varepsilon^{-T_1})\,(1 - \varepsilon^{-(T_2 - a)})}$$

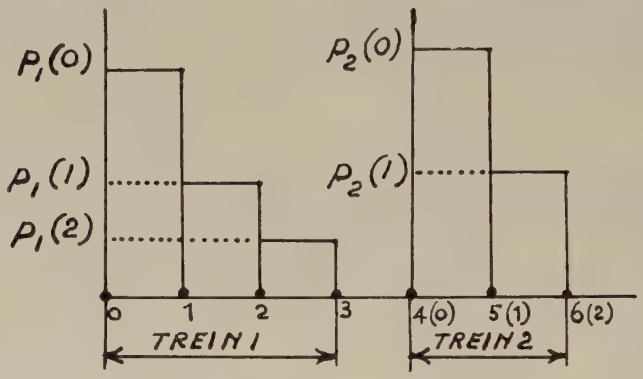
$$\cdot \left\{ \frac{1}{2}\varepsilon^{-(2T_1 + h - a)} + \frac{1}{2}\varepsilon^{-(a - h)} - \varepsilon^{-T_1} \right\}$$

Limit case :

$$a - T_1 = h \rightarrow W = 0 .$$

In order to apply this theory to a practical case, the functions $p_1(t)$ and $p_2(\varepsilon)$ must be determined from the differences in minutes, between the recorded times of

track occupation and the scheduled times. For instance, out of 1 000 trains, so many trains will have been 0 minute, 1 minute, 2 minutes, etc., late, or, rather, will have had a delay from 0'0" to 0'59", from 1'0" to 1'59", from 2'0" to 2'59", etc. The numbers obtained must be divided by the total number of trains recorded. In this way, one obtains, for each time range, the corresponding frequency ratios or, in other words, the subsequently calculated probabilities of the phenomena considered. For simplicity's sake, let us assume a constant elementary probability between successive whole minutes, a situation illustrated below.



The values p_1 and p_2 are determined by the relations :

$$\int_0^{T_1} p_1(t)\,dt = 1 \; ; \qquad \int_0^{T_2-a} p_2(\tau)\,d\tau = 1 \; ;$$

$$p_1(1) = \frac{1}{2}\,p_1(0) \; ;$$

$$p_1(2) = \frac{1}{4}\,p_1(0) \; ; \; p_2(1) = \frac{1}{2}\,p_2(0) \; .$$

One thus obtains :

$$p_1(0) = \frac{12}{7\,T_1} \; ;$$

$$p_1(1) = \frac{6}{7\,T_1} \; ; \; p_1(2) = \frac{3}{7\,T_1} \; ;$$

$$p_2(0) = \frac{4}{3(T_2 - a)} \; ; \; p_2(1) = \frac{2}{3(T_2 - a)} \; .$$

Hence, in the given circumstances :

$$T_2 = 2\,T_1 \; ; \; a = 1\,\frac{1}{3}\,T_1 \; .$$

If, in addition, the crossing occupation time for each of the two trains is assumed to be 3 minutes (e.g. two long, slow-moving goods trains), i.e. $h = T_1$, the probability of clashing works out as follows :

$$\int_{a-h}^{T_1} p_1(t)\,dt \qquad \int_0^{t-a+h} p_2(\tau)\,d\tau =$$

$$\int_{\frac{1}{3}T_1}^{\frac{2}{3}T_1} \frac{6}{7\,T_1}\,dt \left\{ \int_0^{t-\frac{1}{3}T_1} \frac{2}{T_1}\,d\tau + \int_{\frac{2}{3}T_1}^{T_1} \frac{3}{7\,T_1}\,dt \left\{ \int_0^{\frac{1}{3}T_1} \frac{2}{T_1}\,d\tau + \int_{\frac{1}{3}T_1}^{t-\frac{1}{3}T_1} \frac{1}{T_1}\,d\tau \right\} \right. = \frac{2}{21} + \frac{2}{21} + \frac{1}{42} = \frac{3}{14}$$

Although the main purpose of this theory is the study of problems connected with the compilation of timetables (waiting times, interchange connections), the theory may also be applied to the study of carriage siding layouts and the like where many arrivals and departures take place simultaneously.

As the construction costs of tracks, points and crossovers are high, careful planning is essential, and it is highly desirable that, before the construction is proceeded with, the optimum number of tracks and crossings required for a given traffic is determined by theoretical means.

[656 (485)]

The problem of railway and road transport in the economics of Swedish transport.

We publish below with the authorisation of the author, M. Arne Sjöberg, a summary of his article : « Das Problem Eisenbahn — Kraftwagen in der schwedischen Verkehrspolitik », which appeared in No. 3 (1958) of the Review Schweizerisches Archiv für Verkehrswissenschaft und Verkehrspolitik (Annales Suisses d'Economie des Transports), *Zürich.*

I. Origin of the general transport policy.

Since 1920, about which date road transport entered the field of long distance traffic, transport economics which till then only concerned the railways, had to become more general and cover in addition the road and waterways, and more recently aviation. The « Riksdag » was thus led in 1932 to formulate the objectives of Swedish transport policy. Whilst desiring to have competition on equal terms between the different methods of transport, it regulated the road traffic but retained the obligations of the railways which aggravate or hamper competition with the road. At that epoch, it was considered that it was sufficient to put three principles into application :

— rationalisation of the railways by making them state railways;

— rationalisation of the railway tariffs;

— revision of the transport regulations for road transport worked on the owners behalf and modification of the taxes on road traffic.

This programme could not be carried out entirely, especially as regards the rationalisation of the railway tariffs. The second war made it impossible to obtain the expected equilibrium between rail and road traffic.

A general revision of the transport policy became all the more pressing as the post war years were characterised by intensified competition between the two methods of transport.

II. Present obstacles to competition on equal terms.

Far from enjoying equal conditions as regards competition, the railways are subjected to numerous obligations (obligation to carry, to have a reserve of stock to meet peak traffic, to take into account the requirements of the national defence), but above all that of having published tariffs which apply to everyone, for traffic on both profitable and non-profitable lines. The lack of flexibility of the tariffs which do not take into account neither the real costs which differ from line to line, nor the seasons, obviously make it impossible to achieve the lowest possible social cost for transport.

The necessarily average tariffs of the railways are not competitive; on the electrified lines with low costs, they are too

high for the road competition which often parallels them, whilst on the secondary lines, which are often not served by the road in view of the small volume of traffic to be carried, the rates charged are below the costs. From the social point of view, it would however be better to leave this traffic to the road.

Although there is a certain balancing of the costs between the different parts of the country in the case of the road owing to the standard rates, however, in the case of the railway, the balancing of the receipts between the various lines has to cover both the cost of the line itself as well as the operating costs. This is the great difference between the railway and the road.

III. The present traffic position in Sweden.

With 16 400 km (10 190 miles) of railway (i.e. 2 200 km [1 367 miles] per million inhabitants) and 98 000 km (60 894 miles) of roads, more than 18 thousand million tons/km were carried in 1955. The share of transport in the national productivity exceeds 13 %. It is more than 25 % of the State budget. More than 10 % of the workers are engaged in transport.

Between 1935 and 1955, the increase in traffic was 3.5 % each year for the railway and 10 % for road transport and 1 % for navigation. The average transport distance, however, in 1955 was 270 km (167 miles) on the railway and 19 km (12 miles) on the road.

It must also be pointed out that the terrific development of road transport since 1950 has become one of the foremost problems of the social economy, especially on account of the huge capital investments required (more than 40 thousand million crowns in two decades).

The danger of making mistakes in capital investment led the Swedish Government in 1953 to set up a commission charged with carrying out a general examination of the problem.

IV. The new transport policy.

The 1953 Transport Commission had to examine the structure of railway transport costs and road transport costs, the various economic conditions of these transports, in regions with different intensities of traffic, in order to achieve finally rational utilisation and coordination of the different methods of transport. It had to examine the conditions of cost which might lead :

1) to a transfer of certain traffic from the railway to the road and vice versa, with the object of making a rational economic distribution of the traffic, made difficult to date by the diversity of the tariff systems;

2) to an adaptation of the railway system to the new situation created by the great development of road transport, not forgetting to study its capacity to deal with peak traffics.

The directives given to the Commission obviously require every region to have that transport equipment which will assure the traffic being carried at the lowest possible cost and not require any subsidy from the community. In particular, the railway should not have to receive any subsidies and coordination between railway and road should be achieved. Avoiding extreme solutions, the Commission had to look for compromises and combinations of solutions wherever possible.

The examination of the problems by the Commission made it clear that besides retaining the obligations imposed on the railway when it enjoyed a monopoly, quantitative limitations had been imposed on road transport, partly to protect the railway against competition against which it would be powerless, but in this way other monopolies had been created and the desired objective of a balanced general transport was far from being attained.

Must road transport still be governed by licences ? Would it not be better to take steps immediately to divide up the traffic as fairly as possible under conditions of free competition and on equal terms ?

After considering these questions, the Commission pronounced in favour of a solution requiring the minimum of regulations by allowing the maximum of free competition, all conditions being equal between the different methods of transport.

The experience of twenty years of transport policy in Sweden has justified the principle that healthy competition under equal terms is a powerful stimulant for a progressive general development of the economic life of a country. The Commission therefore considers it necessary to develop as far as possible free competition between the different methods of transport under equal conditions.

V. Signification of competition on equal terms for the railway.

Competition on equal terms implies for the railway the giving up of the two fold objective of satisfying its own economic exigencies and at the same time taking into account social considerations and the general policy of the economics of the country. Consequently, the railway will act like a commercial undertaking in the transport field, with great liberty as regards tariffs, kinds of service, the social form of the undertaking, such as the possibility of forming affiliated companies (haulage, stores, etc.).

Looking at the matter in this way, at the end of 1956, the tariffs committee suggested important modifications to the administrative structure of the railway, in particular compensation from the State for lines with little traffic run at a loss, as well as for unjustified reduced tariffs for passengers and freight, and payment for post office and military transport.

A more business-like management appeared capable of achieving the necessary improvement in the financial results. But for this it is necessary to think on commercial lines, both as regards the capital investment and the policy of the undertaking, i.e. the composition of the production, the number of production points, the technique of production, the tariffs, the services offered the public, good-will and the elements affecting the quality of the service. All this can lead at the same time to increased receipts.

The application of this business-like way of thinking will have the effect of :

1) simplifying the operation of the lines, closing down certain lines and in other cases working the services partly or wholly by buses and lorries instead of rail services;

2) concentrating points of production, such as stations, shops, stores;

3) adapting the number and kind of trains more flexibly to demand;

4) making a distinction between profitable traffic and other traffic and taking this into account in the tariffs as well as in the way of dealing with it.

But the most complex problems are those dealt with in the following chapters (VI to IX).

VI. Giving up non-profitable activities.

In 1954, 75 % of the traffic was carried on 25 % of the lines. Closing down the non-profitable railway lines has thus become the cardinal problem of Swedish transport economics. Between 1950 and 1956, they only succeeded in closing down about 550 km (340 miles) of lines.

Just as in industry, where it is clearly appreciated that there must be the necessary concentration in order to increase productivity by giving up the very small undertakings and favouring the growth of export products (total available labour hardly increasing in Sweden), the railway should give up the lines with little traffic and improve the equipment on the principal lines.

Studies have shown that any kilometre of lines which does not carry at least 250 000 traffic units, a year should be closed down for economic reasons alone. This is the case on 6 000 km (3 720 miles), i.e. 40 % of the Swedish railway system. Now 70 % of these 6 000 km are private lines taken over by the State since 1939, whilst the other 30 % are situated in the north of Sweden. The deficit of these lines amounts to 200 million crowns a year.

Giving up these lines, though justified

economically, in certain cases would involve greater costs to the State economy and be harmful for the community. Moreover, the necessary capital for the corresponding improvements to the road network could not be found, nor would the requirements of the national defence be met. A large part of them will therefore have to be kept open.

The railway tariffs committee suggested that a total compensation of 100 million crowns should be paid by the State in order that the deficit from these lines should not have too unfavourable an effect upon the railway's tariff policy. The transport commission agreed to this demand, as it was afraid that if it was not met, road transport would increase still more, without justification moreover, and by this fact involve the community in still greater costs.

A final evaluation of the compensation has not yet been made.

VII. Equipment of the principal railway system and intensification of profitable activities.

It is essential to equip the principal lines in such a way that they can deal with increased traffic and thus earn higher receipts. Rationalisation and mechanisation should make it possible to reduce labour costs, which amount to two thirds of the total operating costs.

VIII. Rationalisation of the tariff structure; greater commercial competency.

The railway tariff committee stated that the tariff structure must be constantly adapted to the constant modifications in technique, costs and competition. The obligations of public carrier should be lightened. The committee also proposed to make changes in the obligation to apply standard tariffs over the whole system and over the whole year, as well as rates based on the distance and values.

It is proposed to introduce special tariffs and special individual reductions. The actual rates can be decided by the railway within the framework of a general tariff fixed by the government. The proposals for the latter have already received various approvals.

This extension of the competence of the railway will be an important stage on the way to establishing competition on equal terms with road transport.

IX. Introduction of a commercial structure to the railway undertaking.

At the present time, the railway is an administration having an economic character but integrated in the general administrative apparatus of the State.

It must however be possible for the railway to adapt constantly its activities and organisation to contingencies arising. This is much easier for a joint stock company, especially as in this case there is much greater freedom in determining the wages and agreements with employees, as well as business matters. The most profitable investments are also chosen better in the case of a joint stock company, especially as regard purchases.

Between State administration with an economic character and a joint stock company, there are many intermediate forms which might be chosen. The transport commission is examining the problem on these lines.

X. Résumé.

In the transport and coordination policy in preparation in Sweden, there seems to be a tendency towards granting the railway equal conditions to those enjoyed by its competitors. It is impossible to indicate at the moment the details of this policy. The present study is merely intended to sketch the relations between the railway and its proper field of action. It must be appreciated that competition between transport undertakings on equal terms as far as possible leads to an economic division of the traffic and minimum costs for the community, much more definitely than is possible with the transport policy followed until recently. P. SCH.

[656 .212 .8 (44)]

Weighing trucks on the move,

by M. Rousse,

Ingénieur, Chef de la Subdivision du Matériel Fixe à la Direction des Installations Fixes de la S.N.C.F.

(*Revue Générale des Chemins de fer*, November 1958.)

The readers of this review will have seen the various notes about weighing wagons whilst moving in America (1).

Moreover, numerous articles have been published about the devices designed by the great American Railroads (2).

All these articles and the report presented in October 1957 by M. LOOMIS, President of the Association of American Railroads (A.A.R.) at Geneva to the European Economic Commission made it clear that the problem of weighing moving wagons has been completely solved in America.

The S.N.C.F., like all other great railways, is very interested in this problem. We therefore think it useful to sum up and compare certain statements concerning the facts in question.

The premises of the problem.

It is not possible to weigh all wagons at the time they are dispatched for various reasons (no weighing equipment at the small stations — delays in offering loaded wagons at departure — difficulties in shunting between inwards and outwards yards, etc.).

This results in under-charging and in pressing demands from the commercial departments for checks to be made.

In the case of shunting difficulties or loading delays, in stations of a certain importance, it is of interest to be able to speed up the weighing operations.

The method consists of weighing the wagons, made up into rakes, with loosened fastenings, at a speed which will give a suitable output. This aspect of the problem has also been dealt with in America (3).

But what happens most often is that there is complete absence of any weighing on departure. Several Administrations (America, Holland, France) then went into the question of making a check at some point that would have to be passed on the run.

The gravity humps of the large marshalling yards would meet such a case geographically.

On the other hand, to make use of them involves certain exigencies which do not always harmonise with the technical resources available.

The use of the gravity hump presupposes in effect that its operating will not be upset in any way.

In particular, it is essential to keep all its installations working at full output. This means a shunting speed of 4 km an hour in the case of our large humps which deal with up to 5 000 wagons a day, and involves shunting without uncoupling the wagons intended for the same ladder track of the marshalling yard.

(1) See « Revue Générale des Chemins de Fer », Nov. 1957 : « Electronic weighing of moving wagons » p. 645. Id., Feb. 1958 : « Mechanisation of marshalling in the U.S.A. — Automatic weighbridges », p. 126.

(2) See Bibliography (« in fine »).

(3) See « Railway Age », April 1957.

This latter point has three consequences :

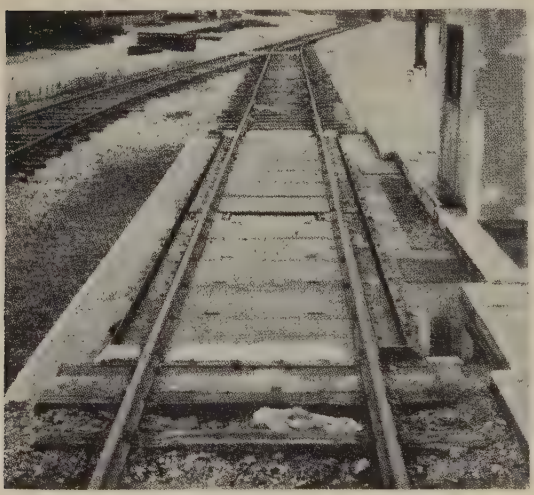
1) to get a certain degree of accuracy, wagons that are weighed without being uncoupled must not be influenced by the adjoining wagons, which means that the fastenings must be loose and the buffers not compressed.

As a result the weighing should preferably take place when the vehicles are running freely down the hump, not when they are coming up it;

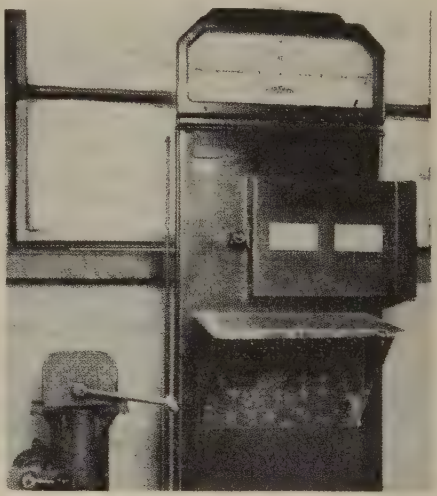
Realisations at the present time.

The *first method* of weighing wagons whilst running, on a holding siding for example, has just been introduced.

The results have been given for some time on the S.N.C.F. by direct readings of automatic mechanical heads, by using coupled bridges (7.50 m + 5 m with a stationary section of 0.50 m), the weighing head being worked by either table or both, by means of a selection lever worked by



The two weigh tables and the stationary section.



The Dubourdieu indicator and the selector.

Fig. 1 and 1 bis. — The coupled weigh tables at Paris-Hébert station (East region).

2) the possibility of keeping several wagons coupled up may make it necessary to weigh the last axles at speeds of as much as 10 km/h.

3) keeping the wagons coupled up and the diversity of the wagons used makes it necessary to consider weighing them axle by axle in view of the fact that the wheelbase varies between 3.5 m and 16 m approximately with two or four axles per wagon.

Having thus set out the premises of the problem, we will consider the solutions put forward to date.

the operator, according to the length of the vehicle (fig. 1 and 1 *bis*).

In practice, such readings are hard to make without error at speeds higher than 1.8 km/h.

In such a case, printing the result must be considered. The lower limit of the time taken to react by the best automatic printing heads of the mechanical type is 2.5 to 3 sec. This seems to make it impossible to go below this with such systems.

The S.N.C.F. using a TOLEDO printing head (fig. 2) has set up an installation

which weighs the axles whilst running in the case of two axled wagons up to a speed of 2.7 km/h which is already useful. If the speed is higher than this, the axles are not weighed, but a blank space is left on the printed band (fig. 3 and 4).

This system uses a short table of 2.60 m known as the « bogie weigher ». Bogie wagons cannot be weighed, unless they are weighed at rest in two stages.

The S.N.C.F. has also had built by the « Société des Ponts Bascules », at Voiron, an ingenious automatic recording head, which gives an impression axle by axle up to speeds of 3.5 km/h (fig. 5 and 5 *bis*).

Finally, the S.N.C.F. always using an automatic head whose time of response will be reduced by limiting the field of observation between 15 and 20 t, has now being

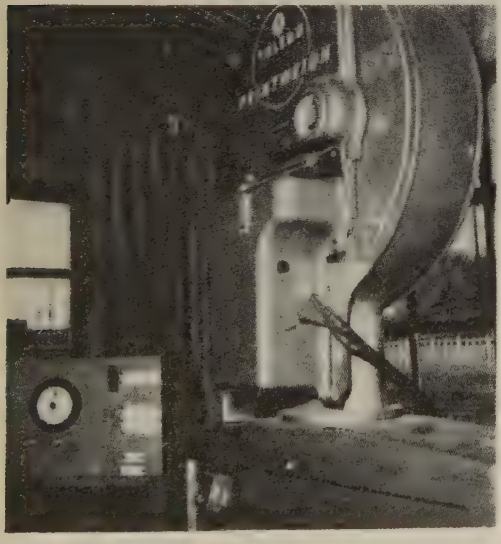


Fig. 2. — Apparatus (Toledo Head).

designed, a device to detect overloaded axles.

This equipment, which will be of the axle weighing type, equipped with a preselecting device for axles with three values, 16, 18 and 20 t, will reveal overloads by light and audible signals.

In America, similar installations are in use in which, however, electronic devices are used.

In view of the fact that such devices

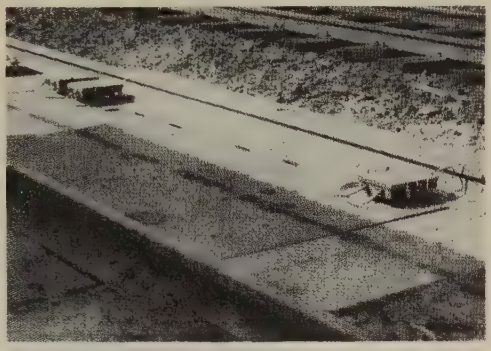


Fig. 3. — Bogie-weigher table with S.I.L.E.C. pedals.

only allow of a weighing speed of 2 to 3 km, it would not appear under present conditions, that they deserve serious attention, since they do not improve upon the performance of good mechanical equip-

0.000 kg

9.850 kg
10.050 kg
15.250 kg
14.900 kg
5.450 kg
5.600 kg

Fig. 4. — Printed band.

ment, although they are more costly and more complicated technically.

But it is the *second method*, that of weighing at the hump, which calls for the most important observations.

Although certain reports and publications from the United States tend to consider the question as completely solved, we think that to make such an affirmation at the present time means that there is a complete difference of opinion concerning the data of the problem.

The reports stated that installations in use weigh accurately wagons running at speeds up to 10 km/h.

But what installations are there in use ?

They are either mechanical (Saint-Luc marshalling yard at Montreal) or electronic.

The installation most often mentioned recently is that of the Kirk marshalling yard of the Elgin Joliet and Eastern Railway, made by the Streeter Amet Company.

This is of a combined mechanical and electronic type, with a primary system of levers acting on a combination of 16 « straingauge » load units.

The manager of the Streeter Amet Cy (1) quotes a time of 2.5 sec in the case of wagons whose length is equal to 20 m, with a weighing table of 27 m length, which presupposes a maximum weighing speed of about 12 km/h.

The average accuracy obtained per wagon is minus 21.6 kg on a total of 169 weighings, with tonnages between 27 and 63 t.

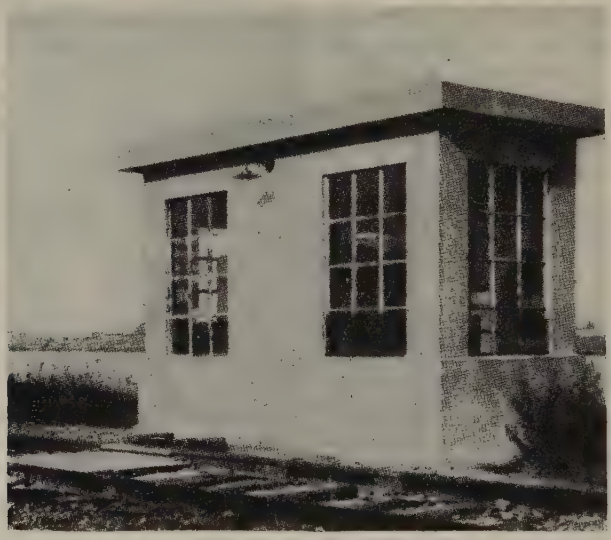


Fig. 5. — Voiron installation. Outside view.

The problems dealt with in the U.S.A. and in France are not comparable.

Why, in view of such results, can we not consider the problem as solved ?

For two reasons :

1) if it is true that the accuracy obtained lies within the tolerances, this is only because the average accuracy is taken but the maximum error has been as much as 4/1 000 (2).

Such errors can only be increased in view of the consequences involved in our second observation;

(1) See « Railway Age », 26th March 1956.

(2) See « Proceedings of the A.R.E.A. », 1956.

2) in the case of all the installation described, both mechanical and electronic, the weighing tables have been very long (27 m at Kirk, 23 m at Saint-Luc).

High speed weighing with the American installations is in effect obtained not by improving the weighing time θ, but by extending the length λ of the table with, approximately, $\lambda \sim V\theta + l$ in which V is the maximum speed of passage and l the longest wheelbase.

fact which may be of less account in America than in France, in view of the use of automatic couplings.

The installation made in France with a concrete table 14 m long at the Narbonne marshalling hump, has therefore not been repeated, although satisfactory as regards accuracy and output (fig. 6).

The need not to uncouple all the wagons makes it necessary to adopt the single method of weighing axle by axle by means

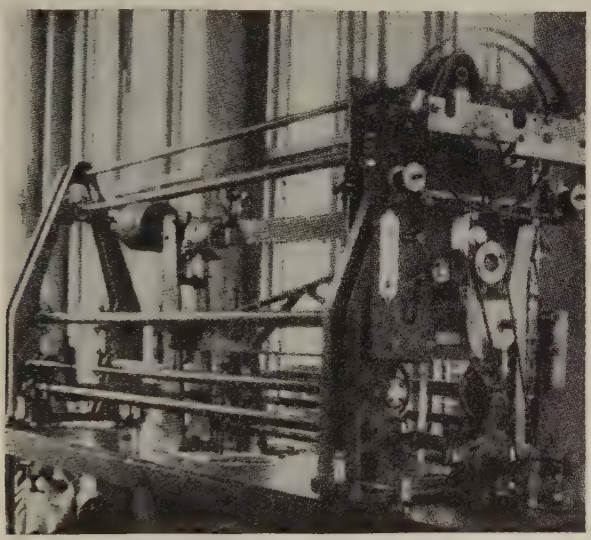


Fig. 5 bis. — Voiron installation. Recording apparatus.

As a result weighing can only be done wagon by wagon and involves uncoupling all the wagons at the hump.

Calculating the shunting speed at the top of the hump, taking into account poor running vehicles and the fact that the following wagon may arrive at the weighing table immediately the latter is cleared by the first axle of the previous wagon, means a possible speed of more than 4 km/h, which therefore is sufficient.

The essential objection as far as France is concerned lies in the fact that the wagons have to be shunted one by one, a

of a 1.60 m table, the smallest wheelbases of bogies rarely being less than 1.675 m.

The idea of a bogie weighing machine also is attractive. Unfortunately, the small minimum distance between the end axles of two adjoining wagons only allows of too short a useful length for the weighing time. The axle weighing solution only allows of a weighing time of 0.5 sec for a maximum speed of 10.8 km/h.

Setting out the problem in this way, and excluding shunting wagon by wagon, there can no longer be any question of improving on the best performance of the

mechanical systems, but it becomes essential to adopt a purely electronic solution giving very rapid response.

Moreover, it must be pointed out that this requirement has not made the problem any easier.

Weighing in two stages has its own errors which in practice make the degree of accuracy unacceptable in the case of bogie wagons.

In the case of two axled wagons, the only case considered, disturbances have a rather unfavourable effect, the shocks at the table joints being multiplied by two, as it is not possible in view of the very short time involved to allow the different parts, whether suspended or not, to become sufficiently stable during weighing.

In the present stage of our researches, such disturbances unfortunately have such an effect that they do not allow of sufficient commercial accuracy.

The elimination of such disturbances appears to present considerable difficulties when it is considered that the measurements made show the existence of a fairly low frequency, with a period of magnitude too close to that of the time of response of the equipment for the working to be accurate and for it to be possible to claim it is an average value.

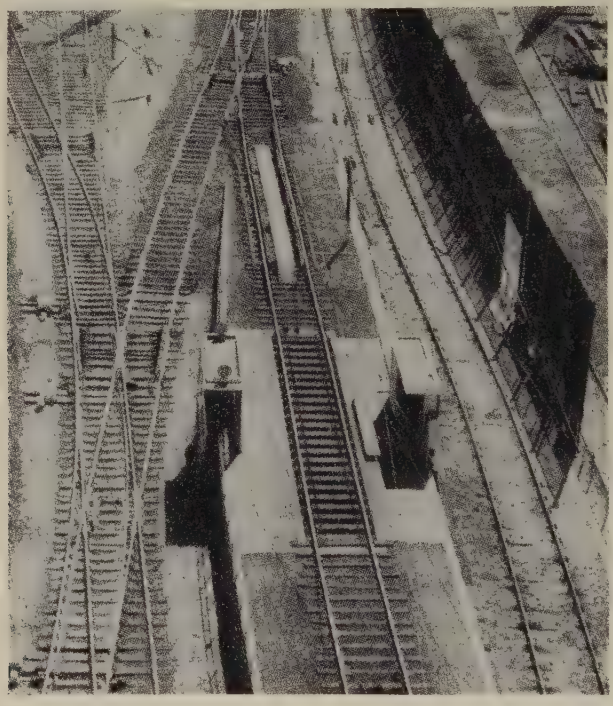


Fig. 6. — Installation at the Narbonne shunting yard.

Conclusion.

To sum up, it appears that the problem of weighing whilst on the move at the hump has been based on different data in America and France, and consequently the

difficulties of the French realisations have been considerably greater.

It is probable that it would be possible to alter the premises of the problem at the expense of the operating conditions at our gravity humps. Even if the general introduction of automatic couplings was considered in Europe, which is not likely in the near future, it would still be rather unrational to uncouple wagons that are to remain together.

Consequently, we must persevere in our attempts to improve the results obtained. But it was useful to recall that as we have not taken the same starting point as the Americans, the resulting difficulties have been different, and it is this and not technical progress, which explains the present gap in the results obtained.

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[656 .2 (460)]

The justification for the General Modernisation Plan and Five Year Programme of the RENFE,

by Manuel Prados y Lopez.

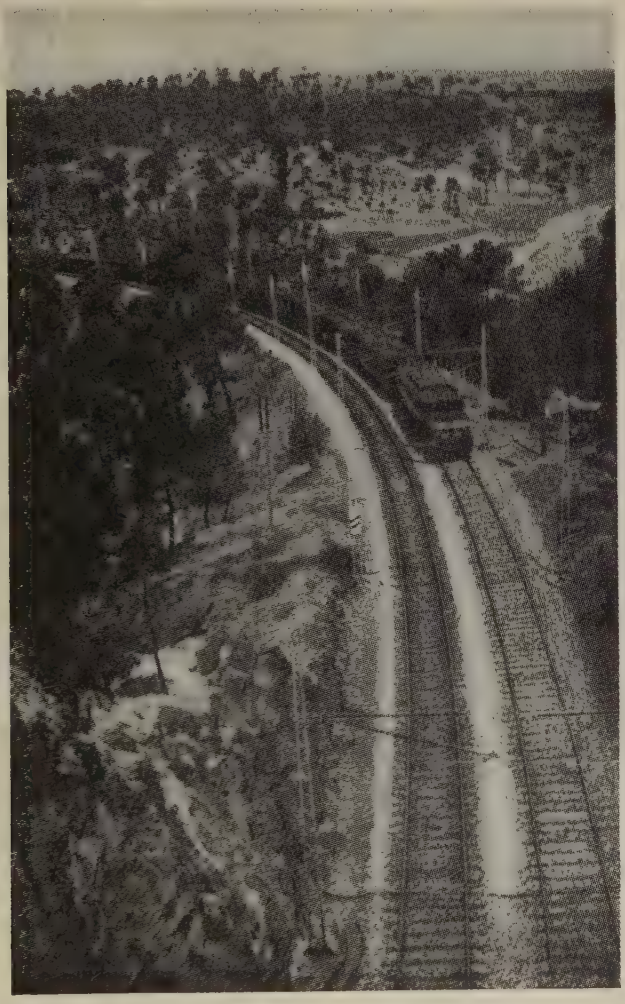
(*Transportes*, No. 63, March-April 1958.)

This documentary and well presented work, published by the RENFE under the brief but suggestive title of « Modernisation Plan » is a further explanatory and statistical proof of the unshakable official determination to make the necessary improvements in railway transport. In the very first line of the « Memoir » with which this interesting volume starts, allusion is made to the efforts made to assure that the services of the RENFE reach the desired level of safety and efficiency.

This work and these efforts are revealed in the Reconstruction Plans which have followed one upon the other; at the present time, the second revised Plan is being carried out.

The estimated costs are increasing at an extraordinary rate because requirements are spreading and the cost of materials and labour have risen to unbelievable heights. Already the original 1946 Plan had to be increased by 3 500 millions in 1949, whilst in 1952 it had reached a figure

An important item of the Plan covers the Shops, Depots and Stores.
Here is the TAF train depot at Cerro Negro (Madrid).



Another item of great interest in the Plan is that of the electrifications. This photograph shows an express train running on a line that has already been electrified.

of 12 711 millions and in 1955, 24 504 millions. A further revision of prices and costs is again needed at the present time.

The same « Memoir » affirms that the railway is « the basic transport method, in spite of other more modern competitors ». The statement is not merely optimistic, but also constructive, based upon a faith which engenders « vocational miracles ».

The total amount of the Plan is 72 353 592 896 pesetas. Deducting the credits granted (17 277 421 947 pesetas), there still remains 55 000 millions in round

figures, which corresponds to what is represented by this new plan for capital investment.

It is not possible to recapitulate in a brief review such a complete and also detailed work as this, every aspect of which would have to be covered to give a faithful synthesis of the technical and economic panorama that this Modernisation Plan represents.

The essential problems are methodically studied. In the chapter dealing with the permanent way, provision is made for the remaking of 4 678 km of lines, in conformity with a classification into three categories. Under this heading, a total sum of 8 518 million pesetas is allocated. 292 717 000 pesetas are allocated for the improvement of the stations. The two sums of the plan relating to steam locomotives correspond to the items for conversion to oil firing and the improvement of the motor stock : 308 millions for fuel and 10 millions for small modifications. The remainder of item *c*) corresponds to the three categories of Diesel locomotives. Provision has been made for purchasing 300 locomotives of each series.

In the same way, important sums have been allocated for trains of the Talgo type or others assuring the same type of service, working fast and luxury runs.

The total of 25 713 wagons, which under the hypothesis of an annual production of 3 000 wagons will provide work for 8 years, gives an idea of the importance given to the improvement of the rolling stock.

The whole of the item for shops, depots, stores and offices amounts to 1 250 527 000 pesetas. The reconstruction of the numerous lines of communication which are unsuitable for the electrified sections is being actively pursued, as well as the making of new high frequency installations. The signalling installations will require 1 161 108 thousand pesetas.

A station of the new line from Zamora to La Corogne.

Another aspect of capital interest in the « Memoir », we are reviewing, is that relating to electrification. The sum total of the expected cost of the revised costs of the second revised plan and the new electrification projects proposed amounts to 20 857 748 160 pesetas. Of this amount, 13 338 384 000 pesetas represent the new plan.

The tables, appendices and résumés

which follow the « Memoir » as well as those given in connection with Chapter II, the « Proposed Five Year Modernisation Plan » add further interest to the work published by the RENFE.

The « Memoir » on the Five Year Plan amply justifies the need thereof. There is some work already in hand, essential and urgent modifications, which cannot be put off without a risk of irremediable ruin in the near future; which is why a choice has been made of the most urgent work, installations and purchases, which form a smaller project within the General Plan, the carrying out of which can be fixed within five years in every case. The amount involved is 24 700 000 000 pesetas.

The details of the Five Year Plan are grouped in this book in the same way as those of the General Plan, i.e. under similar headings, with identical calculations to throw light upon the question and dissipate any uncertainty regarding the different aspects of the problems studied and solved.

The details of the first of the three stages in electrification laid down in the Five Year Plan seem to us of particular interest. The following lines are concerned : Monforte-Ponferrada, with the branch line to Villafranca del Bierzo; Avila-Medina; Hontanares-Medina; Medina Venta de Baños; Venta de Baños-León; Palencia-Alar; Venta de Baños-Burgos-Miranda; Madrid-Alcázar; Madrid-Arcos de Jalón and Port-Bou-Empalme.

The interior of a Talgo train on a curve of small radius. (Large amounts have been allocated for Talgo type trains for fast and luxury services.)

Complete, fundamental, agreeable, and magnificently produced on hand laid paper, this book matches in importance the Plans studied and compared within it. The Spanish Railways awaiting improvement is a national subject of notable preoccupations and well founded hopes. We salute the book, the projects and the technical efforts.

[625 .2 (493) & 625 .28 (493)]

Evolution of rolling stock in Belgium.

During this period of transformation in the rolling stock of numerous railways as well as tramway companies, it appeared of interest to give our readers a few details about the rolling stock of the Belgian National Railways Company (S.N.C.B.) and the Belgian National Light Railways (S.N.C.V.).

These details are taken from the pamphlet « Echos des Communications », No. 1, 1959, published by the Belgian Ministry of Communications.

Railway rolling stock.

The total railway rolling stock as at the 31st December 1957 is shown in Table I.

The evolution undergone by « stock running on rails » is worth stressing.

Originally, enjoying a monopoly in fact, the railways have since had to meet the competition of the motorcar and the aeroplane. Thus the S.N.C.B. found itself forced to undertake improvements to its services and modernisation of its equipment.

From 1938 to 1957, the total number of locomotives decreased from 3 396 to 1 903. The number of steam locomotives fell by more than 50 %, whilst electric and Diesel locomotives made their appearance and increased in numbers (see Table II). The

Table I. — **Railway rolling stock.**

	Traction units			Passenger stock				Freight wagons
	Steam loc.	Electr. loc.	Diesel loc.	Electr. railcars	Diesel railcars	Electr. motor coaches	Coaches	
S.N.C.B.								
Number . . .	1 542	159	202	205	215	—	3 936	70 697
Capacity . .	—	—	—	379 126 passengers				1 568 000 t
S.N.C.V.								
Number . . .	29	—	—	119	—	739	689	4 788
Capacity . .	—	—	—	± 100 000 passengers				42 000 t
Tramways								
Number . . .	—	—	—	—	—	1 568	702	—
Capacity . .	—	—	—	—	—	± 188 000 passengers		—

giving up of steam traction can be explained by the superiority of the other methods of traction, especially as regards the efficient use of the energy employed.

Table II. — **S.N.C.B.** — **Traction units.**

Years	Steam	Electric locomotives	Diesel
1938	3 396	—	—
1949	2 801	2	5
1954	2 050	76	11
1957	1 542	159	202

The progressive suppression of steam traction is projected; it is in fact proposed that during the next ten years more than 600 Diesel locomotives for line services and about 200 Diesel shunting engines as well as 27 electric locomotives will be purchased.

As regards the passenger stock, the number of vehicles has declined by 36 % compared with 1938, though the number of seats has only been reduced by 16 %, the average capacity per coach having increased by 32 %. The number of railcars and electric rail motor coaches has also increased (Table III).

Ordinary coaches still include about 2 000 wooden coaches, which are gradually being replaced and will be practically so when the 760 metal coaches and 60 electric rail motor coaches now under construction

Table III. — **S.N.C.B.** — Passenger stock.

Years	Electric rail motor coaches	Railcars	Ordinary coaches	No. of seats	Average capacity
1938	12	43	6 820	451 563	65
1949	21	144	4 544	324 640	67
1954	62	195	4 301	356 617	78
1957	205	215	3 936	379 126	86

Table IV.

S.N.C.B. — Freight wagons.

Years	Number of wagons	Average tonnage per wagon
1938	98 872	17.70
1949	85 338	19.77
1954	72 902	20.86
1957	70 697	22.18

or provided for in the working programme are put into service (1).

A similar phenomenon occurs in the case of freight wagons. Compared with 1938, the number has fallen by 28 %, whereas the average capacity has increased by 25 % (Table IV). It is proposed that the stock, whose renewal is projected over a period of ten years, will be increased to 60 000 units.

It should be noted, however, that in spite of the effective reduction in the theoretical capacity, the total traffic for 1957 expressed in traffic units (passengers-km + tonnes-km) is 36 % higher than

Table V. — **S.N.C.V. — Evolution of the rolling stock.**

Years	Locomotives	Wagons	Elec. rail motor coaches	Passenger coaches	Rail motor coaches	Buses
1938	481	10 494	1 041	2 242	279	68
1949	350	9 567	1 006	1 803	251	205
1954	55	6 850	885	1 145	220	523
1957	29	4 788	739	689	119	941

Table VI.

Tramways. — Evolution of the rolling stock.

Years	Motor units	Trailers	Trolley-buses	Motor buses
1937	1 750	1 166	87	88
1949	1 628	1 020	164	10
1953	1 625	830	166	62
1957	1 568	702	188	263

that of 1938, i.e. 15 141 millions compared with 11 108 millions.

The S.N.C.V. stock used for the transport of freight has been considerably reduced since 1938, owing to the corresponding reduction in traffic from 70.3 millions t/km in 1938 to 9.5 millions in 1957.

With regard to passenger traffic, both in the case of the light railways and the tramways, the development of the use of bus services and reduction of the railway stock should be noted, which for 1957 compared with 1938 amounted to some 60 % in the case of the S.N.C.V. and 22 % in the case of the tramway companies.

This evolution shows the preference given in the case of urban transport and short distance services, at least in the case of certain services, to road vehicles rather than the railway, the former having the advantages of greater flexibility of working and being more profitable, though this increases the road traffic problems.

Tables V and VI sum up the evolution of the last twenty years graphically.

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(1) ED. NOTE. — Up to May 1st, 1959, the S.N.C.B. has already purchased on this programm :
— order for 12 prototype Diesel locomotives of 1 400 HP;
— order for 30 Diesel shunting locomotives Standards O.R.E. of 650 HP;
— order for 2 Diesel shunting locomotives of 400 HP;
— order for 10 electric locomotives of 2 560 HP (125 km/h);
— order for 6 electric locomotives of 2 810 HP (140 km/h);
— order for 620 coaches for internal services; 300 have already been put into service;
— order for 40 coaches with berths for international services;
— order for 2 prototype coaches for international services;
— order for 38 coaches for secondary lines (built in its own workshops).
In addition, calls for prices have been issued or are being made for the supply of the following :
— 30 Diesel locomotives of 1 900 HP;
— 6 prototype Diesel locomotives of 850 HP;
— 2 prototype high-speed locomotives tri-current (1 500 V, 3 000 V, 25 000 V);
— 60 double electric motorcoaches.

[625 .1 (52)]

Projected standard-gauge line between Tokyo and Osaka.

We give hereafter a résumé of the booklet : « The projected standard-gauge Tokaido Trunk Line », received from the Foreign Department of the Japanese National Railways, supplying details on the construction and operation of the new railway line between Tokyo and Osaka, which, it is hoped, will be achieved in 1961-1962.

The Japanese National Railways have just announced their intention of building a completely new line between Tokyo and Osaka (distance about 500 km = 310 miles). This project, called the *Tokaido Trunk Line,* which is revolutionary from more than one point of view, is described in detail in a booklet : « The Projected Standard-Gauge Tokaido Trunk Line » published in January 1959. The idea is to build a standard-gauge, 1.435 m, line, whereas the whole of the existing railway system in Japan is metre gauge. In addition, the following speeds will be authorised :

	Maximum speed.	Average speed.	Journey time.
Old line . .	150 km/h	110 km/h	4 1/2 h
New line . .	250 km/h	170 km/h	3 h

The line will be electrified with 20 kV, 60 Hz current.

The carrying out of this work is considered absolutely vital for the economy of Japan. In effect, the present line carries in each direction a traffic of 60 to 80 passenger trains and 50 to 60 freight trains daily and is working to saturation. It is estimated that by 1975 the passenger and freight traffic will be at least double than that of 1956, in spite of the fact that allowance has been made in the calculations for the traffic on the high capacity motorway that is going to be built, as well as coastal navigation and even air services. In the region between Tokyo and Osaka live 36 million Japanese (about 40 % of the population) producing 60 % of the total industrial production of the country.

The first projects date back to 1938. Certain sites had already been acquired before the war. The new line which will have a completely new bed from the old, will be about 40 km (25 miles) shorter. But it is interesting to hear the reasons put forward to justify using standard-gauge in Japan : first of all, the transport capacity of the vehicles is higher (about 30 %); then the journey times will be reduced (see above); finally, the cost of construction is estimated to be lower, owing to the absence of any connections by means of points and crossings with the old line; there will not be any level crossings; finally, it opens up the possibility of a completely reorganised method of railway transport in the case of freight, large scale application will be made of semi-trailers on flat wagons, so as to offer « door to door » services.

The cost of the work is estimated to be 479 million dollars. Even if the capital has to be borrowed at 7 % interest, the calculations made indicate that it is possible to expect excellent profits and the capital will be completely repaid 15 years after the work is completed. It is expected that it will be completed for 1961/62.

The Japanese National Railways who will thus shortly have a « super railroad » expect that the great profitability of the new line will considerably facilitate the financial management of the railway, many of whose lines are run at a loss at the present time.

P. SCH.

[656 .22 (73)]

Why the C&NW likes Car-Fax.

(*Railway Age*, May 4, 1959.)

The Chicago & North Western's new Car-Fax system is the largest commercial transceiver network in the world. It keeps tab on car and train movement as they occur, 24 hours a day. At 68 reporting points along the C&NW's 9 300-mile system, waybill and car report information is placed on punched cards. The information goes to Car-Fax headquarters in Chicago. In addition to providing fast, accurate car tracing data, Car-Fax produces — from one source, the waybill — the required control and statistical reports for traffic, operation and accounting. Car-Fax went into full service last January 1. One year was spent planning the system, a second year putting it into service.

Car-Fax is the newest device in Chicago & North Western management's continuing campaign to increase railroad operating efficiency. It costs $1.1 million a year to operate, but the railroad thinks it's worth every penny.

" Car-Fax is North Western's latest step to provide its customers with the finest railroad freight service in the country ", says Ben W. Heineman, C&NW chairman.

Here's what the Car-Fax system provides:

— Fast, accurate car tracing service through Car-Fax headquarters at Chicago, and its traffic offices from coast to coast.

— Fast, accurate reconsignments or diversions of freight en route.

— Immediate information on shipments delayed because of bad order cars.

— Improved car utilization, resulting in availability of more cars of the type and quantity needed, when they are needed.

— Reduced switching time through advanced train consists, allowing advance planning for switching in C&NW yards.

In summary, the principle objective of Car-Fax is to permit preparation of required control and statistical reports for traffic, operations and accounting from one original source. The reports will :

(1) Facilitate traffic department work by providing information necessary for directing and evaluating sales efforts and for better customer service.

(2) Enable the operating department to utilize and move cars more efficiently.

(3) Facilitate accounting for revenues and for car per diem.

The first and most obvious benefit of Car-Fax to the traffic department is car tracing information. " Flash " listings of train consists are posted hourly in the Car-Fax information center at Chicago. The listings cover arrivals, departures and interchange of some 50 000 cars moving over North Western lines daily.

In addition to the " flash " listings, a central tracing record is compiled daily (cut off time : 11 p.m.). This record, available the first thing each morning, shows all car movements of the previous day and the last location of each car on the railroad. Copies of a simplified version of this report are airmailed to 60 traffic offices throughout the country.

Car-Fax prepares various other reports, such as car loadings by commodity and state origin and state destination. Many of these reports are prepared daily and show cumulative totals as well as comparisons with the previous year. These reports indicate traffic trends. The promptness with which they are received enables the traffic department to take immediate action.

Because Car-Fax reports train and car movements as they occur, a whole new area of better car distribution and utilization is open to the operating department. North

Western men like the Car-Fax system to a quality control system used in manufacturing industries. Reports about empty cars on line, terminal car detention, empty car location reports, bad order reports of cars set out and then released after repair, interchange reports, and train operation summary reports are a few of the many the system makes available to the operating department. Some reports present the information by divisions, so that management always has an up-to-date picture of operations on the entire railroad.

" Car-Fax ", said one North Western man, " places the general manager in every yard office. " Why ? Because many of these daily reports are on management's desk first thing each morning, making the previous day's activities known. Thus the operating department can " be on top of the situation " at all times.

Car-Fax integrates revenue accounting requirements with fast, accurate car reporting. This is so because the waybill information is put on a punched card at the origin point, or where the car is received in interchange. Waybill information is sent via transceiver to Car-Fax headquarters at Chicago, where it is reproduced on punched cards. Cards containing waybill revenue information are sent to the accounting department for machine processing.

A daily unearned revenue report shows the potential revenue value of cars originated and received from connections by commodities. This report helps management project revenue values of loadings. From the day to day trend, management can predict future earnings, which is helpful in budgeting programs.

Of great interest is a daily per diem report the system provides. With 50 000 cars operating over C&NW daily, management knows the per diem charges, broken down by divisions. C&NW management believes the report will make division superintendents more per diem conscious which, in turn, will spur them to better car utilization.

North Western has 68 mechanized reporting yards (black dots on map) in its Car-Fax system.

Car-Fax future is unlimited.

The future for Car-Fax, according to North Western management, is unlimited. What it can do is not really predicted at the present time, except to say... " the more we live with it, the more we learn about it. We can see areas where studies need to be made concerning car movements, loadings, car distribution and utilization, for which Car-Fax is providing the basic information today ".

According to Mr. Heineman, the railroads are " turning to true competitive pricing ". Railroads have not gone into cost pricing, says Mr. Heineman, " because of the huge volume of transactions, and mechanical equipment has not been available. However, this is no longer an excuse. Today there is ample mechanical and electronic equipment to enable us to carry out in pricing anything our brains can originate. I am talking about substantial rate reductions in many areas ".

On the North Western, Car-Fax is the mechanical and electronic equipment and system available for producing prompt, accurate information regarding train movements. From the system North Western management believes it will be able to make some pertinent and informative cost pricing studies. Management believes the Car-Fax system will enable it to eliminate many special movement studies that are made from time to time, with the objective of finding out if a possible rate adjustment can be made for a particular commodity over a particular move. Now this information is available daily. As one man remarked, it is simply a matter of collating the proper punched cards and running them through an accounting machine to produce a report.

A fast, basic communications system is established with Car-Fax. As the railroad becomes more proficient in operation of the system, some believe that it will be possible to use Car-Fax to obtain more than information about car and train movements.

How Car-Fax operates.

Punched cards are prepared at the 68 Car-Fax field stations, which are known as mechanized yards. Each mechanized yard prepares punched cards for : (1) cars loaded locally; (2) cars received locally from connecting lines; (3) cars arriving in trains for which cards have not been prepared at some other mechanized yard; (4) cars departing empty, either in trains or delivered to connecting lines after unloading locally; and (5) car movements reported from non-mechanized yards. In this latter category, interchange reports are mailed from the smaller interchange stations to the nearest mechanized yard for card punching and transmission of the information to Car-Fax headquarters at Chicago.

Transceivers at Car-Fax headquarters in Chicago receive car-report information from each of the 68 mechanized yards.

Two cards are punched for each car. A third card will be punched with special handling instructions, if applicable. Punched cards are prepared for empties as well as loads. The No. 1 card contains all information necessary for advance train consists and interchange reports. The No. 2 card contains revenue accounting information and the route. A duplicate of the No. 1 card is automatically made on the card punch and placed with the waybill. The other copy of the No. 1 card and the No. 2 card are set aside for accumulating all new loads to be reported to the Car-Fax headquarters. Cards on new loads normally are accumulated and transmitted between 10 p.m. and 3 a.m. to Car-Fax headquarters in Chicago.

For train departures from initial terminals, a No. 1 punched card for each car and a No. 3 card, special instructions where applicable, are needed to report the train's departure. Before departure of the train, punched cards are arranged in train order from the head end. If cars are to be set out en route, divider cards are placed in front and behind cards for any cars to be set out at an intermediate mechanized yard. Car-Fax headquarters can therefore identify cars to be set out, and will relay this information to the proper yard. The deck of cards for the train, with a header card giving train information, is run through an accounting machine, which prepares the conductor's wheel report. The conductor takes with him two copies of the wheel report and the freight waybills.

After the train departs, the deck of cards (with the header card and a caboose card indicating the time of departure, conductor's name, etc.), is put in the IBM transceiver. Next, the operator, using the phone circuit associated with the transceiver, calls Car-Fax headquarters, telling them that the yard is ready to send a train consist report on the train's departure. The operator at Car-Fax headquarters will "dial" the yard onto the circuit so transmission can be started.

The transceivers operate at the rate of 10 cards per minute. Thus, it takes only 10 or 15 minutes to handle a train consist. When transmission is completed, cards at Car-Fax headquarters are used for preparing the various reports. A flash listing is prepared by putting the cards through an accounting machine. This listing is given to Car-Fax tracing headquarters in an adjacent office.

Car-Fax headquarters also takes the cards which pertain to cars to be set out at an intermediate point. The cards, with the appropriate header card to indicate the train number and train information, are placed in an IBM transceiver for transmission to the intermediate yard. A clerk uses the phone circuit associated with the transceiver circuit to call the intermediate yard, telling them that he has a list of cars to be set out. The yard clerk sees that his transceiver is loaded with blank punch cards, and tells the Car-Fax headquarters clerk to send. After dialing the transceiver, the operator at Chicago presses a start button and the punched card information is sent to the intermediate yard.

If cars are to be picked up at an intermediate yard by this train, the yard will prepare punched cards for the cars to be picked up, and, with an appropriate header card, will transmit the information to Chicago.

The Chicago headquarters relays the information concerning cars pickel up at an intermediate yard and also cars set out at an intermediate yard, to the final or terminal yard for the train. The train consist as sent from the initial yard on the train's departure, is relayed by Car-Fax headquarters to the terminal yard (destination of train). From these consist cards, an advance train consist and switch list is prepared, enabling the yardmaster to preplan his switching operations.

After the train arrives and cards are made out for cars not previously having cards, the cards are arranged into groups representing all cars which move between the same two stations. A divider card is inserted in front of each card group to indicate the station from, the station to, and miles. The cards are then used to transmit arrival information to Chicago. These groups of cards are preceded by a header card of train informa-

tion and followed by a caboose card and an end-of-report card.

From idea to fact in two years.

North Western management began planning for Car-Fax in 1957. That entire year was spent with the accounting firm of Arthur Andersen & Co. working out the plans and details of the Car-Fax system. Also working with the railroad were International Business Machines Corporation, which furnished the transceiver and data processing equipment, and American Telephone & Telegraph Co., whose circuits are used. The railroad is leasing the IBM equipment and AT&T circuits.

One of the big problems in planning such an installation was where to locate the mechanized field stations. One object of the system, of course, is to " catch " as many cars as possible each day. As presently set up, all time freights originate and terminate at one of the field stations. Individual cars may pass several field stations a day. Hence, it is common to have the central tracing record show a freight car passing through two or more yards.

Field stations were selected on the basis of train movement and were located where train movements were concentrated. This, of course, included interchange points. Although the North Western has 222 interchange points, 80 % of interchange movements occur at the Car-Fax stations.

The study and planning for Car-Fax was completed by the end of 1957. The system was installed during 1958. First transceiver installations were in South Dakota and Wyoming, the west end of the railroad. Simultaneously, Car-Fax headquarters was set up at the Ravenswood accounting office in Chicago. To be of any use even to the first field station, Car-Fax headquarters had to be able to receive punched card information and process it. Traffic is lightest at the west end of the C&NW system.

As personnel both at the field stations and at Car-Fax headquarters became accustomed to handling greater volume of punched cards, installation was able to proceed more rapidly. One of the next Car-Fax stations to be put in service was at Proviso yard, the North Western's large retarder classification yard just west of Chicago. All field stations have one transceiver, except Proviso and Butler, Wis., which have two each. Twenty transceivers are in Car-Fax headquarters in Chicago. Up to four stations can be handled at once on one transceiver circuit.

Most Car-Fax field stations are in previously existing structures, such as freighthouses, yard offices or passenger stations. In nearly all cases, the buildings were rehabilitated, at least to the extent of installing air conditioning. In some cases, sound deadening material in the ceilings, and fluorescent or new lighting, was installed. At Crystal Lake, Ill., one-half of the passenger station waiting room was utilized for the Car-Fax field station. At Fortieth Street, Chicago, a new building was constructed which also houses the local agent's offices as well as welfare facilities. Most offices have air conditioning, which is desirable for operation of the transceivers and other IBM data processing equipment.

As with any new system, extensive training was needed to enable C&NW personnel to operate Car-Fax. As expected, the system required additional personnel, not only at Car-Fax headquarters in Chicago, but at some of the field stations. In late 1957, North Western set up a group of 25 instructors who took a five-week course in Chicago on Car-Fax operations, and also in accounting methods and procedures. The course included instruction by IBM on use of its equipment. The 25 instructors supervised the installation and setting up of the Car-Fax field stations, and trained the clerks and telegraphers to use the transceivers and IBM equipment at the 68 stations. The training program is continuing. Other North Western personnel working in the Car-Fax system are taking additional training in integrated data processing.

NEW BOOKS AND PUBLICATIONS.

[385 .08 (494)]

Rapport de gestion de l'Union d'Entreprises Suisses de Transport. — Année 1958. — *(Management Report of the Swiss Transport Undertakings Union. — 1958.)* — A brochure (8 1/4 × 11 1/2 in.) of 118 pages, illustrated. — 1959, Union d'Entreprises Suisses de Transport, Bundesgasse, 28, Berne.

The management report, which the *Union d'Entreprises Suisses de Transport* has just published, sums up the activities of this organisation in 1958 and reports the important questions in the discussion of which it took part.

After having characterised the general evolution of the traffic, which suffered on the one hand from the economic recession, and on the other hand from the ever increasing competition of road transport, the report comments on the new Swiss legislation on transport and in particular the law of the 20th December 1957 on the railways, which came into force on the 1st July 1958.

It then studies the repercussions of a reduction in working hours on the operating of the private railways and stresses the need for complete cooperation between the staff and the management in order to arrive at a satisfactory solution in each particular case.

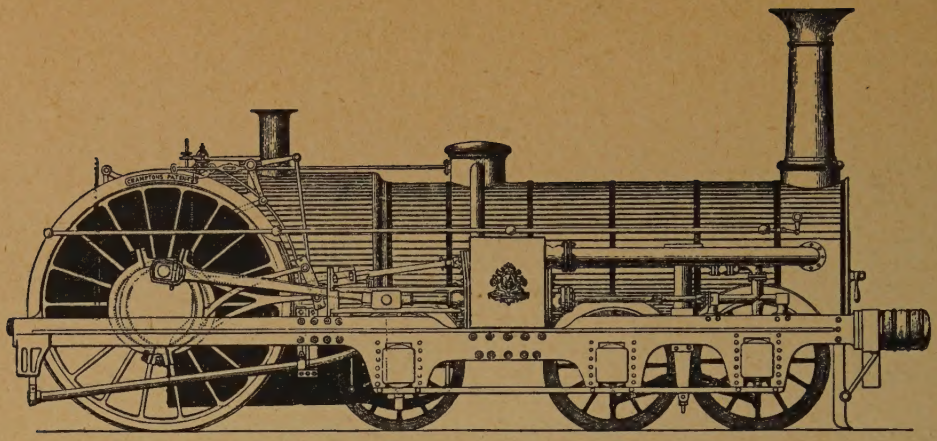
Tariff problems are also the subject of a detailed examination, in which the revision of the tariffs projected for 1959 is defended.

The question of the coordination of rail and road transport is then mentioned, stressing the need to give, by legislation, a solution to the difficult problems arising in order to safeguard the interests of the railway undertakings.

The report ends with an examination of the position of urban transport, cable railways and navigation, as well as a summary of the current activities of the Union.

In conclusion, it expresses a somewhat pessimistic opinion on the future perspectives of the traffic in general, in view of the increased charges it will have to bear in the near future whilst, in view of the development of tourism, it views the future of the tourist railways and navigation undertakings with greater confidence.

R. S.



OVER 100 YEARS AGO

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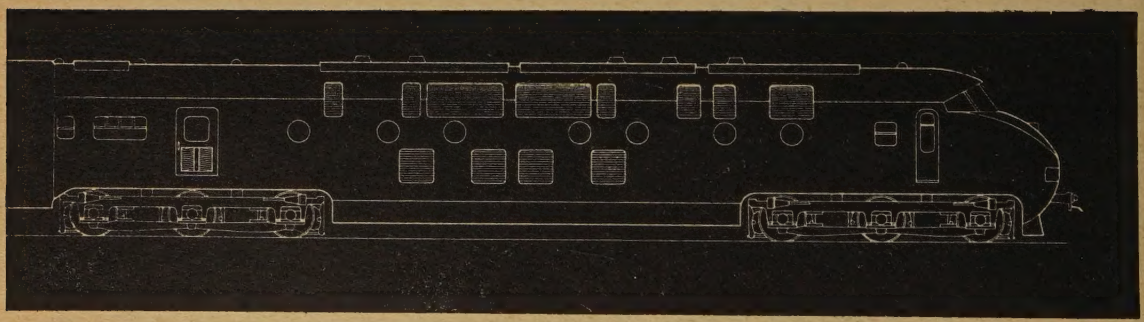

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